

LIBRARY
N. Y. UNIV.

NATIONAL RESEARCH COUNCIL

TRANSACTIONS OF THE AMERICAN GEOPHYSICAL UNION
THIRTEENTH ANNUAL MEETING
APRIL 28 AND 29, 1932
WASHINGTON, D. C.

PUBLISHED BY THE NATIONAL RESEARCH COUNCIL
OF
THE NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D. C.
JUNE, 1932

QE
500
A6
V.13
1932

CONTENTS

	PAGE
INTRODUCTION.	3
REPORTS AND PAPERS	
GENERAL ASSEMBLY.	5
Resolutions adopted.	7
Symposium on the application of geophysics to ocean-basins and margins	11
SECTION OF GEODESY.	51
Reports and papers	53
SECTION OF SEISMOLOGY	89
Symposium on the application of seismology to the study of ocean-basins.	91
SECTION OF METEOROLOGY.	111
Reports and papers	113
SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY.	143
Reports on magnetic and electric work of organizations in the United States during 1931-32.	145
Papers	159
SECTION OF OCEANOGRAPHY	193
Reports and papers	195
SECTION OF VOLCANOLOGY.	265
Papers	267
SECTION OF HYDROLOGY.	275
Reports of permanent committees.	277
Papers	313

[For detailed list of contents for each meeting in the above order,
see pages 6, 52, 90, 112, 144, 194, 266, and 276]

By Transfer
Coast & Geodetic Survey

MAY 15 1936

INTRODUCTION

The American Geophysical Union is the American National Committee of the International Union of Geodesy and Geophysics, and the Executive Committee of the American Geophysical Union is the Committee on Geophysics of the National Research Council. The objects of the Union are to promote the study of problems concerned with the figure and physics of the Earth, to initiate and coordinate researches which depend upon international and national cooperation, and to provide for their scientific discussion and publication. In the accomplishment of these objects, the Union is divided into sections following the plan of organization of the International Union of Geodesy and Geophysics. There are now seven sections, namely, (a) Geodesy, (b) Seismology, (c) Meteorology, (d) Terrestrial Magnetism and Electricity, (e) Oceanography, (f) Volcanology, and (g) Hydrology. A Section of Geophysical Chemistry was discontinued May 31, 1924, as the International Union had failed to provide such a Section; the Section of Hydrology was established November 15, 1930--matters pertaining to scientific hydrology referred to the American Geophysical Union had been previously looked after by special committees on hydrology.

Annual assemblies of the Union and annual meetings of its sections for the discussion of reports and symposia are held each year. Thus far there have been thirteen such assemblies and meetings, all held in Washington, D. C. The transactions of these annual assemblies and meetings through the ninth were published in the Bulletin series of the National Research Council as follows: Second, 1921, Bulletin No. 17; fourth, 1923, Bulletin No. 41; sixth, 1925, Bulletin No. 53; seventh, 1926, Bulletin No. 56; eighth, 1927, Bulletin No. 61; and ninth, 1929, Bulletin No. 68. Transactions of the tenth and eleventh annual assemblies and meetings held in 1929 and 1930, respectively, were published in June 1930 and those of the twelfth annual assembly held in 1931 were published in June 1931 in the series of miscellaneous publications of the National Research Council. The present Volume, also one of the miscellaneous publications of the Council, includes the transactions of the thirteenth annual assembly. At the first, third, and fifth annual meetings in 1920, 1922, and 1924, respectively, there were no scientific papers presented; therefore, the transactions for these were not printed but were mimeographed for limited distribution only.

The thirteenth annual assembly of the Union and of the meetings of its sections, April 28-29, 1932, was held at Washington, D. C., in the building of the National Academy of Sciences and National Research Council, except for two of the three meetings of the Section of Hydrology which were held in the conference-room of the Geological Survey in the building of the Department of Interior.

Following a brief business meeting, the session of the thirteenth general assembly was devoted to a Symposium on the Application of Geophysics to Ocean-Basins and Margins, the symposium being followed by an illuminating discussion with constructive comments. The individual section meetings were marked by numerous progress-reports on geophysical activities, not only in the United States, but also in Canada and in Mexico. The Section of Geodesy, following such progress-reports, discussed gravity-work, isostasy, instrumental developments, the Moon's influence on latitude, and aerial photogrammetry. In the Section of Seismology the meeting was given over to a Symposium on the Application of Seismology to the Study of Ocean-Basins. In the Section of Meteorology accounts of the programs arranged for the Second International Polar Year of 1932-33 and for the solar eclipse of August 31, 1932, were followed by papers bearing on winds in the upper atmosphere and in the antarctic, on atmospheric turbidity and water-vapor, on interrelations between air- and ocean-temperatures in California and the northeast Pacific, on weather-charts of the northern hemisphere, and on a half-century of American rainfall. In the Section of Terrestrial Magnetism and Electricity the reports of organizations regarding American activities in its fields during the past year were followed by papers relating to ionization of the upper atmosphere, its radio exploration, and geophysical significance, to conducting-layer measurements at Little America, to periodicities in radio-transmission phenomena, to cosmic radio correlations, to slow-moving ions of the atmosphere, to lightning-discharges and the electrical fields of thunder-storms, and to instrumental progress. The communications to the Section of Oceanography, besides progress-reports showing the development of oceanographical work in the United States by governmental and private organizations, included discussions of light-penetration into the sea, of formation of submarine

162374

valleys, of oceanic surveys of temperatures and the temperature-gradients in oceanic waters, of Arctic and Atlantic interchanges, of radium-content of ocean-bottom sediments, of microbiology and marine limestone, and of oceanographic centers and methods of northwest Europe. In the Section of Volcanology the papers dealt with Central American volcanoes in 1932, with volcanic developments in 1931-32, and with volatility of silica with steam. The Section of Hydrology devoted the morning, afternoon, and evening of April 28 to hearing reports of its nine permanent committees and 21 papers submitted by authors from federal governmental, state governmental, university, and consulting engineering organizations. These covered numerous investigations and developments in scientific hydrology throughout the United States. They serve also to illustrate how widespread and how effective is the cooperation of American hydrologists.

Communications from members of the national committees of our neighbors in Canada and Mexico showed continued active international cooperation between those countries and the United States, and reported on the progress of governmental activities and on results of geophysical researches stimulated by the national committees.

On behalf of the Executive Committee of the Union, cordial thanks are tendered the speakers, guests, and members of the Union for the active interest which made possible the success of the thirteenth annual meeting of the Union--the large attendance and constructive discussions during which afforded material evidence of the rapidly expanding interest in geophysics in America.

The preparation of the final manuscript for direct reproduction in this volume was done by J. J. Capello. The funds for publication have been supplied in part from the allotment made by the National Research Council for the maintenance of the Union and in part from the annual dues of members of the Union.

J. A. Fleming,

General Secretary

AMERICAN GEOPHYSICAL UNION
Thirteenth Annual Meeting

REPORTS AND PAPERS

GENERAL ASSEMBLY

Washington, D. C.
April 29, 1932

CONTENTS

	PAGE
GENERAL ASSEMBLY.	5
Resolutions adopted.	7
Resolution on the urgent need of continuing oceanographic work without material curtailment	7
Resolution on gravity-work at sea by United States Navy	7
Resolution regarding the purchase of apparatus for determining gravity at sea.	7
Resolution on Naval Observatory time-signals.	8
Resolution on the need of non-governmental research institutions in meteorology.	8
Resolution in commendation of geophysical abstracts, published as an information circular of the U. S. Bureau of Mines	8
Second International Polar Year 1932-33	9
Resolution on the death of Alfred Judson Henry.	9
Resolution on the death of Robert DeCourcy Ward	9
Resolution on the death of Louis Agricola Bauer	9
Symposium on the application of geophysics to ocean basins and margins	11
Introduction. Richard M. Field	11
Problems of island-arcs and ocean-deeps. Walter H. Bucher.	12
The structure of the Bartlett Trough. Stephen Taber.	19
Seismic zones as related to relief of ocean-bottom. N. H. Heck	21
Interpretation of gravity-anomalies and sounding-profiles obtained in the West Indies by the International Expedition to the West Indies in 1932. Harry Hammond Hess	26
Sounding the depths of the ocean for mapping the conformation and topography of the bottom. G. W. Littlehales.	33
The applications of seismic methods to submarine geology. E. DeGolyer.	37
Torsion-balance surveys in southwest Louisiana and southeast Texas. D. C. Barton	40
Experiences of a seismologist with "seismic methods." A. L. Day.	42
Discussion following symposium.	45

RESOLUTIONS ADOPTED

(I) RESOLUTION ON THE URGENT NEED OF CONTINUING OCEANOGRAPHIC WORK WITHOUT MATERIAL CURTAILMENT

(Proposed by General Assembly)

WHEREAS, The great value of the oceanographic survey-work conducted by various bureaus of the Government is universally recognized, and

WHEREAS, Any appreciable curtailment of this work would result in a real loss to geophysics from both practical and theoretical points of view, therefore be it

RESOLVED, That the American Geophysical Union hereby expresses its appreciation of the value of the oceanographic work conducted by various bureaus of the Government, and be it further

RESOLVED, That it urges, in accommodating governmental activities to necessarily reduced budgets, there should be no disproportionate curtailment in appropriations devoted to this part of the Government's service, and be it further

RESOLVED, That copies of this resolution be sent to the President of the United States, to the Secretary of Commerce, to the Secretary of the Navy, and to the Secretary of the Treasury.

(II) RESOLUTION ON GRAVITY-WORK AT SEA BY UNITED STATES NAVY

(Proposed by Section of Geodesy)

WHEREAS, Results of great scientific value have been obtained by observations of gravity at sea in the waters of the West Indies and adjacent regions by the two expeditions of the United States Navy, the first in 1928 and the second in 1932, and

WHEREAS, Satisfactory determinations of gravity at sea can be obtained only on board of a submerged submarine, therefore be it

RESOLVED, That the American Geophysical Union of the National Research Council expresses its high appreciation to the United States Navy Department for its contribution to science in making available submarines for the important work of determining gravity at sea and its hearty thanks to the officers and crew of these submarines for their able and ready cooperation, and be it further

RESOLVED, That the American Geophysical Union expresses the hope that the United States Navy will continue to contribute to this important scientific work by placing, whenever practicable, a submarine at the disposal of properly equipped observers desiring to undertake work of this sort, either in the waters adjacent to the United States or in mid-ocean, and be it further

RESOLVED, That copies of this resolution be sent to the President of the United States and to the Secretary of the United States Navy.

(III) RESOLUTION REGARDING THE PURCHASE OF APPARATUS FOR DETERMINING GRAVITY AT SEA

(Proposed by Section of Geodesy)

WHEREAS, The determination of gravity at sea has long been recognized by scientific men as a means of discovering geophysical and geological facts of great value and importance in ocean-areas, and

WHEREAS, The determination of gravity at sea with an accuracy approaching that attainable on land has repeatedly been proved to be possible, if carried out with a suitable multiple-pendulum apparatus on board a submarine, and has again been demonstrated by the observations aboard the U.S. submarine S-48, on the recent expedition to the waters of the West Indies during February and March, 1932, and

WHEREAS, The results of the several gravity-at-sea expeditions, on which the special multiple-pendulum apparatus has been used, have confirmed the high expectations of the scientific public, therefore be it

RESOLVED, That the American Geophysical Union of the National Research Council expresses the hope that an apparatus of the multiple-pendulum type may soon be secured by some organization or institution in this country, for use on submarines of our Navy, and be it further

RESOLVED, That copies of this resolution be sent to the President of the United States, to the Secretary of the United States Navy, and be distributed otherwise as, in the opinion of the Chairman of the National Research Council, may seem expedient.

(IV) RESOLUTION ON NAVAL OBSERVATORY TIME-SIGNALS

(Proposed by sections of Geodesy and of Seismology)

WHEREAS, Organizations represented in several sections of the American Geophysical Union have benefited by the increase in the number of standard time-signals broadcast daily by the United States Navy during the past year, therefore be it

RESOLVED, That the American Geophysical Union expresses its hearty appreciation of the action of the United States Navy, especially the U. S. Naval Observatory and the Naval Communications Service, in furnishing this valuable time-service, and be it further

RESOLVED, That the United States Navy be requested to increase still further, if possible, the number of daily signals when conditions permit it to do so, and be it further

RESOLVED, That copies of this resolution be sent to the Secretary of the Navy, to the Superintendent of the U. S. Naval Observatory, and to the Director of Naval Communications.

(V) RESOLUTION ON THE NEED OF NON-GOVERNMENTAL RESEARCH INSTITUTIONS IN METEOROLOGY

(Proposed by Section of Meteorology)

WHEREAS, Urgent need exists for the training of students in advanced meteorological work, and

WHEREAS, Incident to the development of aviation and other lines of commercial activity, greater need exists than heretofore for the services of trained meteorologists, and corresponding opportunities for employment arise in civil and governmental departments, therefore be it

RESOLVED, That the American Geophysical Union expresses the hope that colleges and other educational institutions will provide for courses in advanced meteorology, and be it also

RESOLVED, That the Union specifically indorses the progress that has already been made along this line by the Massachusetts Institute of Technology, and urges the need for its continuance and ample support, and be it further

RESOLVED, That a copy of this resolution be sent to the President of the Massachusetts Institute of Technology.

(VI) RESOLUTION IN COMMENDATION OF GEOPHYSICAL ABSTRACTS, PUBLISHED AS AN INFORMATION CIRCULAR OF THE U. S. BUREAU OF MINES

(Proposed by Section of Terrestrial Magnetism and Electricity)

WHEREAS, The growth of interest in geophysics in recent years both from the practical and from the basic point of view has been very rapid, the extensive and increasing literature on this subject being scattered about in a large number of journals, and

WHEREAS, The "Geophysical Abstracts" compiled and published by the U. S. Bureau of Mines is supplying an important need by providing a helpful review and directory of the literature of geophysics, therefore be it

RESOLVED, That the American Geophysical Union hereby commends this undertaking and expresses its hope that the compilation and publication of the "Geophysical Abstracts" may be continued and extended, if possible, and be it further

RESOLVED, That a copy of this resolution be sent to the Director of the U. S. Bureau of Mines.

(VII) SECOND INTERNATIONAL POLAR YEAR 1932-33

(Proposed by Section of Oceanography)

WHEREAS, During the Second International Polar Year 1932-33 various meteorological, magnetic, and hydrographical observations are to be made simultaneously in many widely separated regions by organizations representing various countries, and

WHEREAS, The United States Coast Guard has, in connection with the International Ice-Patrol Service and the Marion Expedition, obtained much valuable scientific data in the region of the Grand Bank and Davis Strait, and has the physical equipment and personnel suitable for continuing this work, therefore be it

RESOLVED, That the American Geophysical Union expresses its high appreciation of this work and its hope that the United States Coast Guard will find it possible to undertake further determinations during the Second International Polar Year of the interchange of water between the Arctic and Atlantic Oceans in the region of the Grand Bank and Davis Strait, and incidentally make such meteorological and magnetic observations as may be practical, and be it further

RESOLVED, That a copy of this resolution be sent to the President of the United States, to the Secretary of the Treasury, to Admiral F. C. Billard, Commandant of the United States Coast Guard, and to Dr. D. la Cour, President of the International Commission of the Polar Year 1932-33.

(VIII) RESOLUTION ON THE DEATH OF ALFRED JUDSON HENRY

(Proposed by Section of Meteorology)

WHEREAS, The death of Alfred Judson Henry has removed from the American Geophysical Union a member who has taken a particularly active part in its organization, especially in the organization of its Section of Meteorology, which he served as Secretary and in many other ways, and

WHEREAS, He rendered conspicuous service to geophysics through a series of notable contributions, particularly in climatology, forecasting, and the relations between weather and floods, therefore be it

RESOLVED, That the American Geophysical Union records its sense of great loss in the death of Alfred Judson Henry, not only because of his scientific attainments but also because of his fine personal qualities, and be it further

RESOLVED, That a copy of this resolution be sent to Mrs. Henry.

(IX) RESOLUTION ON THE DEATH OF ROBERT DECOURCY WARD

(Proposed by Section of Meteorology)

WHEREAS, In the death of Robert DeCourcy Ward, the American Geophysical Union has lost a member who, as a pioneer in the teaching of climatology and as an author of several outstanding authoritative works in this subject, particularly *The Climates of the United States*, has contributed notably to geophysical science, and

WHEREAS, Professor Ward was possessed of a particularly attractive personality and a high sense of honor and right, therefore be it

RESOLVED, That the American Geophysical Union expresses its sense of profound sorrow on the loss of Robert DeCourcy Ward, distinguished scientist and splendid citizen, and be it further

RESOLVED, That copies of this resolution be sent to Professor Ward's family and to the President of Harvard University.

(X) RESOLUTION ON THE DEATH OF LOUIS AGRICOLA BAUER

(Proposed by Section of Terrestrial Magnetism and Electricity)

WHEREAS, The American Geophysical Union has learned with profound regret of the death of Louis Agricola Bauer, founder and late director emeritus of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, and mindful of the

active interest which he has taken in the affairs of the Union and of the important services he has rendered in the advancement of geophysics, particularly in the initiation and conduct of a magnetic survey of the Earth and in the analysis of the results thus obtained, therefore be it

RESOLVED, That the American Geophysical Union, in general meeting assembled, records this expression of its sense of loss in the death of Louis Agricola Bauer, and be it further

RESOLVED, That copies of this resolution be sent to Dr. Bauer's family, to the President of the Carnegie Institution of Washington, and to the Acting Director of the Department of Terrestrial Magnetism.

SYMPOSIUM ON THE APPLICATION OF GEOPHYSICS
TO OCEAN BASINS AND MARGINS

INTRODUCTION

Richard M. Field

The last few years have seen a remarkable growth of interest in oceanography. The formation and endowment of the Woods Hole Oceanographic Institution, the reorganization of the Bermuda Station, and the activities of the Scripps Institution may be cited as a few of the achievements in which the American institutions have played an active part. The publications of a number of marine laboratories here and abroad show that they are investigating several problems which are of fundamental interest to the geologist as well as to the biologist. Of special mention are studies in marine sedimentation and, to a certain extent, submarine configuration.

I have not the time here, nor do I consider that I am by any means the person most fitted, to elaborate the numerous problems in the habitat, migration, and general ecology of living marine organisms, which are not only of great scientific and practical interest in themselves, but which have an exceedingly important bearing upon stratigraphical geology. Today our leading paleontologists are no longer merely cataloguers of fossils--especially new species--but are primarily concerned with the use of fossils in tracing the contemporaneity of faunas in widely separated areas, as well as migratory routes. Hence, in the case of the marine formations which form such an important element in the geological record, not only because of their bulk but also because of their correlative value, the paleontologist-stratigrapher is vitally concerned in the tracing of the boundaries of ancient seas; epicontinental, epeiric, and geosynclinal. Leaders in the subject of paleogeography and paleo-oceanography, such as Schuchert, Ulrich, and others, are known to have a detailed knowledge of literally thousands of Paleozoic marine fossils and it has been whispered that there is at hand more information regarding the marine ecology from the Pre-Cambrian to the Tertiary than that associated with our present marine sediments. I think it may be justly claimed therefore that stratigraphical geologists are deeply interested in much that pertains to oceanography according to the great geological principle laid down by Sir Charles Lyell that it is only through the study of present-day processes that we can hope to determine what has happened in the past. It has been by sticking to this principle of research that geology has raised itself from the slough of catastrophism and approached the dignity of science. It must be admitted, however, that geology is probably the least circumscribed of all the sciences and is rather an attempt to study the structure and history of our planet, using as its tools chemistry, physics, and biology. It naturally follows therefore that modern geology must itself be split into a number of branches, not only because of the special phases of the subject but in order that the investigator may constantly keep in touch with the living and dynamic branch of his science--the paleo-oceanographer must keep pace with the oceanographer.

Thanks particularly to the life-long labors of Schuchert and others we have a large number of paleogeographic maps literally showing the ebb and flow of continental seas of North America from the Pre-Cambrian to the Pleistocene. These maps are founded upon the accumulation of an immense amount of paleontological and geological data. It is an interesting fact, that in practically all cases, stratigraphically successive faunas in any region are not related to each other but that each fauna is an invasion which has either replaced the older fauna or mingled with it. Further, we have cases of contemporaneous faunas and facies which are strikingly different but only a few miles apart. Such is the case of the Ordovician which borders the Atlantic Basin. Here the two facies are divided and were controlled by a well-defined geanticlinal arc stretching from the Scottish Highlands to the Appalachians. Hence, in modern stratigraphy the ecology and migration of marine faunas becomes an exceedingly important factor and the construction of paleogeographic maps must take into consideration the probable ancient migrating routes of the now fossil marine organisms. Oceanic basins would appear not only at present, but also in the past, to interfere seriously with the migration of shallow-water benthonic organisms and, hence, the geologist is forced to postulate land bridges, or resort to still more extreme hypotheses, such as drifting continents or rafting. It is at this point that the stratigrapher (paleo-oceanographer) has not only to meet the criticism of the oceanographer and marine

biologist but also of his nearer relative, the structural geologist. Perhaps it is unfortunate that the history of American geology shows that structural geology and stratigraphy have been treated too much as separate subjects. It has only been within recent years that the interdependence of the two have been thoroughly recognized. This is perhaps one of the reasons why the European ideas regarding geosynclinal seas and mountain building are apparently somewhat diverse from our own. Is it not quite probable that this diversity of opinion may eventually be an important stimulus to the necessity of more cooperative research?

It is hoped that the above preamble may serve to warrant the following statements:

The geologist can suggest a number of problems in the study of present-day oceans and ocean-basins which have a direct bearing upon the solution of geological problems. The question is, who is to tackle them, for the lone worker can accomplish little in this field. These problems in the study of existing oceans may be roughly divided into two major categories:

- (a) Biological--Marine organisms and their environment, or marine biology in its broadest sense, and
- (b) Physical--The structure and configuration of ocean-basins and their margins.

The structure and configuration of ocean-basins and their margins is a fundamental geological problem of interest not only to the biologist and paleobiologist but also to the geodesist, geomorphologist, and structural geologist.

The question may well be asked: Are our marine biological laboratories designed to promote the structural studies of ocean-basins? Finally, the principal methods of attacking the problem are by means of the different branches of geophysics. Geophysics, as its name implies, is concerned with the structure and composition of the geoid. Besides the geophysicists, there are a number of geologists who are adapting geophysical methods to the solution of their problems, and by far the greater number of these appear to be the petroleum geologists. The program of papers to be presented at this symposium has been arranged with a view to further emphasize the importance of this phase of oceanographic research not only from the point of view of the relation of geophysical methods to marine geological problems but also the development of a reasonably sound method of attack.

Princeton University,
Princeton, New Jersey.

PROBLEMS OF ISLAND-ARCS AND OCEAN-DEEPS

Walter H. Bucher

The larger problems of island-arcs and ocean-deeps arise from a few basic facts which may be stated concisely as follows:

First, the linear form of the island-arc and deep-sea troughs stands in contrast to the non-linear swells and basins of the normal sea-floor.

Second, island-arcs and deep-sea troughs occur side by side in close proximity, with the troughs frequently appearing as fore-deeps on the convex side of the arc, but not necessarily so. The deep-sea trough occasionally lies on the concave side, as in the Banda arc, or it swings from one island arc to another as in the case of the Bougainville trough between the New Britain and Bougainville Island.

Third, in ground-plan these linear surface-forms tend toward an arcuate pattern. Two types are particularly noteworthy: (a) Linked arcs, as Suess has called them, such as the island-arcs of the eastern Asiatic shore (the echelon pattern within these arcs to which Tokuda has called special attention cannot be discussed in this brief paper). (b) Hairpin curves, such as that of the lesser Antilles, or the Banda arc.

Fourth, the geological structure visible in the islands shows evidence of relatively recent tangential compression, that is, horizontal movements, as in the folds of the West and East Indies and the thrust-sheets of Timor. Raised shore-lines and coral reefs, on the other hand, indicate recent vertical movements.

Fifth, the main island-arc of the East Indian Archipelago, the only one studied in sufficient detail so far, shows exceptionally large negative gravity-anomalies aligned in a narrow belt which parallels the arc without being confined either to the axes of the islands or of the marginal deep. There are no exceptionally large positive anomalies.

If we had an adequate, comprehensive picture of the mechanics of crustal deformation, we would understand why these properties exist and why they are combined in this fashion. The fact is, geologists have so far been able to do little more than guess at the reasons for these properties of island-arcs and ocean-deeps. The suggestions offered follow such radically different lines that it is evident that we lack the very keys to the problem. The reason for this is equally clear. We are uncertain about the fundamental properties of the crust and its materials.

We do not know whether or not sufficiently large differences in strength exist between the acid "continental" masses to allow them to move differentially, that is, to "drift" through the basic "oceanic" materials.

We do not know whether or not it is possible for units of the Earth's surface to be lowered from a continental level to that of the ocean-floor or vice versa.

We do not know whether the area of the surface of the crust has been constant for geological periods or whether it has undergone a change, and if so, whether there has been a contraction or an expansion.

We do not know whether or not the crust is strong enough to react to Earth-wide stresses as a whole.

We are still ignorant because we lack the observational data from which to build our basic concepts. The following brief remarks are offered at the beginning of this symposium to show how much the geologist is dependent for the formulation of basic concepts on the help of the geophysicist. The problems of the island-arcs and ocean-deeps are here used to show the lines along which critical data may be secured that will ultimately replace our ignorance with knowledge.

(I) Turning first to the question of large horizontal differences in strength existing between continental and oceanic areas, we note the following. Not one of the characteristics of island-arcs and ocean-deeps listed above is limited to the floor of the sea. Ranges bordered by deep troughs (filled with sediments) are the counterpart on the continental levels to the island-arcs and deep-sea troughs. These welts and furrows, as we may call them, generally stand in the same contrast to swells and basins on land as on the sea-floor. The arcuate form is as characteristic of welts on land as in oceanic areas. The mighty sweep of the Alpine welts through the Apennines into the Western Alps and from the Eastern Alps through the Carpathians into the Balkan Mountains may serve as an example. The arc which leads, in our own West, from the Sangre de Cristo Mountains through the Sawatch Range into the Uinta Mountains is linked with the Wasatch Mountain axis as the arc of the Kurile Islands is linked with that outlined by Sakhalin, Yezo, and Honshu. And the hairpin curve in which the Atlas Mountains swing past Gibraltar into the Betic Cordillera of Spain is the counterpart of that of the lesser Antilles.

While there seems to be some difference in scale between the topographic features of the sea-floor and the continental surfaces which may be significant, there is no difference in kind. This seems to lead to but one conclusion. The ocean-floor and the continental surfaces were deformed by the same forces in the same way. The conclusion seems inevitable that the lateral distribution of strength in the crust is of the same order of magnitude throughout.

The force of this argument depends on the degree of accuracy with which the pattern of deformation is known on the ocean-floor and on continents. For purposes of

comparison with the continents, the existing maps of submarine topography are largely inadequate. For the largest parts of the oceans they are still useless for this purpose. We look to the oceanographer for detailed contour-maps of critically chosen parts of the ocean-floor. From the geophysicist using seismic methods, on the other hand, we hope to get subsurface contour-maps of critically chosen continental regions where the deformed surface of the Pre-Cambrian peneplain, deeply buried beneath later sediments, alone can give us an adequate picture of the pattern of crustal deformation.

(II) The second doubt, whether it is possible for parts of continental surfaces to be depressed to the level of the deep sea, is the direct result of those geophysical studies which have led to the concept of isostasy.

Gravimetric surveys have shown that there must be a large change in the strength of the rock materials in a radial direction vertically downward. The condition of isostasy, of a tendency toward gravitative equilibrium, requires that an outer crust of considerable strength, and therefore relatively slow to yield under stress, be underlain by a subcrustal zone with little strength, relatively quick to yield under stress. At a depth probably not greater than one hundred kilometers, the strength may be assumed to drop to a minimum in what Barrell has called the asthenosphere.

If the crust, even where it is strongest, is still so weak as to yield to gravitative stresses even where deviations from isostatic equilibrium are small, then it is indeed very difficult to see how parts of continental surfaces could be lowered to the level of ocean-floors. The critical analysis of much more numerous gravimetric data than are now available will give a sounder basis for reasoning along these lines.

There is, however, a direct approach to this problem which seems to have been overlooked so far. On opposite sides of the North Atlantic Ocean the folded belts of two Paleozoic Mountain systems disappear beneath the sea in Newfoundland and in Cornwall. Existing maps of the intervening ocean-floor suggest strongly that linear topographic elements, submarine ranges, and parallel linear depressions exist along the line connecting the loose ends of these mountain belts. A detailed mapping of the zone in question, or at least of selected parts of it, would contribute information more basic for our understanding of the mechanics of crustal deformation than any other investigation in sight. First of all, if submarine mountain ranges exist in that zone, it is obvious that the two exposed loose ends of the mountain belts have not been connected in the past and have not drifted apart. From the vertical and horizontal dimensions of the submerged topography, furthermore, it will probably be possible to tell if the submerged ranges are erosion remnants like those of the present Appalachians, or if they represent uneroded submarine mountain welts. If that is possible, we shall know in this instance at least whether here a continental surface has been depressed to oceanic depths or if that portion has been sea-floor since Paleozoic times. The writer can only hope that American oceanographers will recognize the value of this investigation and will find means to undertake it soon.

The recent detailed submarine mapping executed by the International Expedition to the Bahamas has proven that the deep troughs which furrow the Bahama Plateau have the shape of a valley system suggesting a tectonized pattern. If it is true that such valley systems can only originate through stream erosion on land, proof has been brought that vertical downward displacement on a large scale is possible. The importance of these studies for the formulation of our basic concepts of diastrophism can not be overestimated.

(III) The last two points of doubt call for a more extensive discussion. They may be discussed together.

On the continents where they are accessible to study, we find that the swells of today were the basins of yesterday, and the mountain welts were raised from geosynclinal furrows; and the basins and furrows of yesterday had been high places at still earlier times. Since welts and furrows, basins and swells are, then, not permanent features of the face of the Earth, they must owe their existence to a deformation of the crust.

The conclusion to which geologists have come long ago seems inevitable, that tangential stresses acting on this crust against the leveling tendencies of gravity, as expressed in isostatic behavior, are responsible for this deformation. Since upward bulging, folding, and overthrusting all offer clear evidence of the action of compressive stresses, it is generally held that compression is a constant and permanent state within the Earth's crust.

Four observations have led the speaker to doubt the adequacy of this concept, and have led him to a different view.

(1) All welts show more or less clearly the effects of two forces, as stated above for the island-arc, namely, one of tangential compression, which produced folds and overthrusts--often on gigantic scales--and one of vertical adjustment which has lifted the worn-down stumps of the folds and the erosion-remnants of thrust-sheets high above their former levels.

The action of both of these forces is subject to rhythmic changes. The speaker considers the evidence convincing that the intensity of tangential compression varies in the crust in the form of a complex rhythm, reaching its maxima in orogenic episodes separated by longer intervals of quiet.

A similar rhythm also dominates the purely vertical movements. Relatively short times of maximum relief alternate with longer intervals in which the relief on the continents is at a minimum, and the continents worn down to featureless peneplains. A corresponding rhythmic change of vertical adjustment takes place at the same time between the largest units of the Earth's surface, the continents, and ocean-floors. At the times when the surface of the continents shows least relief, the seas transgress widely across them, rising sufficiently to lay down on the warping continental platform sediments one to several thousand feet thick. It is as if the vertical distance between continental surfaces and ocean-floors had been decreased during such times.

In the opposite phase of the rhythm, the crustal relief increases. Like gigantic stairways, raised coastal terraces surround our shores and those of the other continents in the present day of nearly perfect isostatic adjustment, while the deeply submerged erosion-platforms of the coral islands of the Pacific indicate a widespread (though not uniform) depression of that great sea-floor.

It is as if epochs of increased sensitiveness of gravitative adjustment alternated with longer intervals of decreased sensitiveness. A suggestion to this effect was made by Willis and Barrell two decades ago. Since the crust remains the same, the change must be due to a change in the physical properties of the subcrustal asthenosphere, possibly in a change of its density.

When we compare the incidence in time of the rhythmic changes in the intensity of compression with that of the changes in crustal relief, we find that maxima of tangential compression coincide with maxima of crustal relief, while the times of great marine transgressions, that is, of minimum crustal relief, are free from orogenic movements.

It is as if the asthenosphere were subject to volume-changes resulting alternately in crustal tension and compression. Since by definition the crust possesses a certain amount of strength and is therefore relatively slow to fail, shrinkage of subcrustal matter would produce tangential compression within the crust and, because of the partial relief of pressure, a decrease in viscosity and therefore greater mobility in the asthenosphere which would lead to more perfect gravitative adjustment, that is, to the increased crustal relief characteristic of epochs of compression.

An increase in the volume of the asthenosphere, on the other hand, would not only relieve tangential compression in the crust but by necessity subject the crust to tension. At the same time, again because of the relative strength of the crust, it would increase the viscosity of the asthenosphere and thus permit the relatively great deviations from gravitative equilibrium so characteristic of the times between epochs of compression.

(2) Welts and furrows do not occur scattered over the surface of the Earth at random. During any limited unit of geologic time, such as the present, for instance, they are confined to a few relatively narrow belts which run continuously for enormous distances across the face of the Earth. Wherever the end of one belt dips beneath the sea, there exists across the water another loose end of a belt which by its stratigraphic and structural history betrays at least a dynamic if not a topographic connection with its counterpart. These mobile belts of the present Earth form a definite pattern. The most conspicuous property of this pattern is that it bears no direct relation to the continental borders. The mighty chains of the Rocky Mountains or of the Tien Shan are as independent of the continental borders as the island-arc of the Bonin and Ladrone Islands.

The pattern is characterized by a peculiar asymmetry. On one side of the globe it centers in the greatest mountain knot of the globe, the Hindu Kush and Pamirs from which several lines of welts diverge. One runs westward through Iran and Asia into Europe and Northern Africa. Another runs northeast through the heart of Asia, through the Altai and to the Transbaikalian mountains and on northeastward. Short, mighty branches form the two gigantic arcs of the Tien Shan and Kuenlun mountains. A third major branch leads through the Himalayas and the Burmese chains into the great island-arc that swings from Sumatra to the Banda Sea.

A fourth one emerges south of the Run of Kutch and forms the mighty welt of the Laccadive, Maldives, and Chagros islands. A fifth one, marked by deep, sediment-filled furrows but no great welts, should be included, the belt that runs from the Aral and Caspian Sea north alongside the Ural Mountains.

On the opposite side of the globe lies a large segment of the crust, the Pacific Ocean, completely surrounded by welts which on the west side lie draped in the famous garlands of island-arcs.

To the writer the world-wide fling of these mobile belts indicates that they owe their origin to stresses that acted on the crust as a whole. When the writer tried to reproduce this pattern by hydraulic compression of spherical shells he found to his surprise that he was unable to do so. He used two kinds of materials, representing extremes of brittleness and relative thickness, (1) thin glass shells and (2) relatively thick spherical shells of paraffine immersed in warm water.

Both materials, on the other hand, when fractured by allowing water to freeze in them, produced automatically precisely the pattern wanted. From one point a number of fractures radiate outward. Because of inevitable irregularities, these lines become deflected before they have gone more than half across the sphere and so come to circumscribe an irregular segment which lies more or less antipodal with reference to the focal point from which they started.

There is, then, a distinct family resemblance between the pattern produced in a spherical shell by tension and that of the mobile belts of the Earth. While the pattern of the mobile belts thus points to tensional stresses for its origin, the effects of crustal compression are evident throughout these belts. This again suggests the possibility that the diastrophic history of the Earth has been one of alternating periods of tension and of compression of the crust.

(3) As early as 1859 Hall observed that welts arise along or within furrows, or geosynclines, as he said, that is, not only do furrows border on welts, but the furrows come first. Those who think of the furrows as being merely due to a down-bending effect exerted by a rising welt will find it difficult to account, for instance, for the enormous thickness of dolomites and limestones of shallow-water origin which fill the Cambro-Ordovician geosyncline of the Appalachian and Arbuckle regions. Careful consideration of a number of typical regions has convinced the speaker that Hall was right. The furrow appears first. Compression later causes the margin of the furrow to buckle up into a welt which eventually overrides the furrow.

If compression is responsible for the local thickening and folding of the crust which forms the welts, the suggestion is justified that the furrows represent a local thinning of the crust, much as a steel bar strained beyond the elastic limit yields by local thinning. Crustal tension would be responsible for the geosynclines, while com-

pression would result in the transformation of the geosynclinal margins into folded mountains.

(4) Mobile belts, like all products of crustal deformation, come into existence, go through a period of active deformation and then cease to function, while new mobile belts spring into existence. The remarkable fact is that the geosynclinal furrows which initiate the new mobile belts frequently cut across the trends of the older ones at all angles. Thus the Mesozoic-Cenozoic Alpine belt of Europe cuts across the trend lines of the late Paleozoic mobile belt in striking fashion. The Sub-Betic geosyncline of Spain, bordered on the southeast by the Betic cordillera, developed nearly at right-angles to the Paleozoic folds of the Sierra Morena, exactly as the modern Mississippi embayment cuts across the folds of the Ouachita Mountains. At two points the Alpine welts grew right across the axis of the late Paleozoic geosyncline, in Asturias and in Silesia. The Mesozoic-Cenozoic Rocky Mountain front intersects at right-angles the southwestern continuation of the Ouachita folds, west of the Marathon Mountains in Texas. Such an intersection of new and old mobile belts seems unintelligible under the assumption that the crust has been continuously in a state of compression while it follows inevitably from the assumption of a rhythmic alternation of compression and tension in the crust.

(IV) These four lines of evidence seem to point strongly to the existence of an alternate expansion and contraction of subcrustal matter in the Earth: (1) The rhythmic alternation of times of least vertical relief, large deviations from isostatic equilibrium and of world-wide transgressions of the sea on to the continents on the one hand, and of times of greatest vertical relief, smallest deviations from isostatic equilibrium, and of world-wide regressions of the sea on the other hand. (2) The pattern of the mobile belts which in detail as well as in its large aspects points to tensional stresses, while it exhibits the effects of compression almost everywhere. (3) The alternation of geosynclinal and of orogenic times. (4) The manner in which new mobile belts intersect older ones.

The generalizations on which this reasoning is based require much further testing and elaboration of details before the tentative hypothesis to which they have led can be accepted. They represent the phase of the problem of diastrophism which geological studies alone can clear up. They are treated in detail by the speaker in a book now in the press.

(V) This ends the chief purpose of this paper. But it is instructive to follow out the tentative hypothesis sketched above, to show how an understanding of the problems of any structural detail of the Earth's surface, such as that of the island-arc and ocean-deeps, must ultimately result from a basic concept of diastrophism derived inductively from all geological and geophysical data concerning the crust. If we accept for the moment the hypothesis outlined above, we arrive at the following picture.

When the Earth's crust is placed under tension by subcrustal expansion, it yields along a few zones, within which numerous furrows come into existence which vary greatly in length and depth. The furrows need not be topographically continuous within these zones any more than the cracks in an asphalt pavement are continuous, and yet the belts will be units in a dynamic sense. Near the surface, yielding takes place along inclined shear-planes. Along the line of yielding the thickness of the material which constituted the crust before the yielding is reduced. This causes an equivalent amount of the subcrustal matter to become part of the crust along the line of yielding. As heavier matter is thus added below, the resulting furrow shows no negative anomalies. The amount of yielding will vary greatly, resulting in a variable depth.

When the sign of the stresses within the crust is reversed and compression takes the place of tension, the action of the compressive stresses is localized along the furrows, as stresses in a board are localized along notches. Welts arise alongside and within the furrows. For obvious reasons the concave side of an arcuate furrow is forced up into a welt under ordinary circumstances. But where stress relations are more complicated, welts may be formed bearing any possible relation to the furrows.

The rising welts tend to over-ride the depression. On land where the furrows are filled with sediments the outward urge of the welt produces marginal folding. Beneath

the sea, where the furrows are largely empty, it must produce submarine slides and superficial topographic changes peculiar to this condition. The deeper the furrow, the higher the welt will rise locally, leading to the condition so characteristic of all welts and furrows.

One remarkable fact clearly shown in all terrestrial welts is frequently overlooked. The total amount of material forced upward in the course of folding and thrusting is a very small fraction of the quantity that had to be removed from the cross-section of the crust in order to permit the amount of shortening observed. Either our picture of the crust is wrong or the bulk of material that is expelled from the crust in the process of shortening is expelled downward.

The isostatic adjustment of folded mountains shows that they mark places at which the density of the crust has been lessened. If in the shortening of the crust most of the crustal matter is expelled downward, the heaviest lower portion is withdrawn from the crust. This causes the folded belts of the crust to become lighter automatically.

The narrow belt of unusually large negative gravity-anomalies which Dr. Meiness has shown to exist in the East Indian archipelago seems to mark the location of such a belt along which active downward thickening of the acid materials of the outer crust is now going on. The curious fact that this belt does not find topographic expression may be taken to indicate that isostatic adjustment is not possible while the downward expulsion of matter is under way, as Dr. Meiness has pointed out. The full significance of these belts of exceptionally large negative anomalies will be realized only when they have been traced systematically in all parts of the Earth's surface.

According to this interpretation, the pattern of island-arcs, as seen in ground-plan, is determined by that of the furrows. This applies to the details as well as to the pattern as a whole. Suess long ago called attention to the ease with which the pattern of linked arcs is produced under tension, as for instance in asphalt pavements. In order to produce a similar pattern experimentally by compression, it is necessary to resort to differential movements of relatively small units of the crust. This is the essence of Hobbs' experiments with locally congealed balsam on contracting rubber sheets and of R. T. Chamberlin's experiments with plugs forced horizontally into sheets of plastic materials, which are essentially like Tokuda's demonstrations of wrinkles produced with one finger on wet tissue-paper. If the definition of the crust is correct on which the preceding discussion was based, it is difficult to see why any small unit, viewed across the whole thickness of the crust, should be sufficiently more rigid than the rest to act as plunger nor is it easy to find a reason why it should move differentially.

The hairpin curves also find a simpler explanation under the conditions of tension. In the small-scale experiments, where fractures take the place of furrows, cross-fractures generally form where two cracks run parallel a relatively short distance apart. If a similar explanation were to apply to the original pattern of furrows, later compression might well raise welts in the form we actually see them on the face of the Earth. In that case there should be evidence to show that the parallel lines of welts tend to run on beyond the connecting line. This is actually the case at Gibraltar where at least the southern line of welts, the Atlas Mountains, runs on far beyond the hairpin curve, vanishing from sight beneath the waves of the Atlantic at Cape Chir. There are suggestions of a similar condition on Trinidad and in the arc of the Lesser Antilles.

The introduction of new hypothetical ideas is justified only if it opens ways for testing the ideas and thereby stimulates the purposeful, directed accumulation of facts. So many new hypotheses have been introduced in the last twenty years that geologists everywhere recognize that further progress can only come from the addition of new and critical information. Much of this needed information lies in the field of geophysics.

This meeting is evidence of the growing recognition of the need of concerted planning of investigations along converging lines from which alone we can hope to

obtain that body of sound information without which satisfactory understanding is impossible.

University of Cincinnati,
Cincinnati, Ohio

THE STRUCTURE OF THE BARTLETT TROUGH

Stephen Taber

The Bartlett Trough is one of the major structural and physiographic features of the Caribbean region. It extends in a flat arc, convex toward the north, from the Gulf of Honduras eastward as far as Gonaïve Gulf between the two western peninsulas of Haiti, a distance of over 1,000 miles. The width, between Cuba and Jamaica, is nearly 100 miles, and the deepest sounding, according to recent reports, is about 4,000 fathoms, or 31,000 feet below the higher peaks of the Sierra Maestra in Cuba and the Blue Mountains in Jamaica.

Three theories have been advanced in explanation of this great submarine trough. It has been attributed to (1) stream-erosion, (2) down-folding, and (3) faulting. The first theory has been abandoned, and it is now generally agreed that the great Trough is tectonic in origin.

The rectilinear course, great height, and precipitous slopes of the scarps that inclose the Trough, together with the abrupt changes in slope at top and bottom, are indicative of faulting rather than folding; and the subsidiary troughs found along the base of the scarps are a characteristic feature of fault topography. The earthquakes that occur with relative frequency along the borders of the Trough, prove that faulting is going on at the present time; and the sea-waves which accompany many of these shocks indicate that the displacements are vertical.

During the past winter, the writer made a study of the structural geology of the Sierra Maestra (in this investigation the author was aided by a grant from the National Research Council), the mountains that extend along the south coast of Cuba and form the northern rim of the Bartlett Trough for a distance of 240 miles. The structure and the topography of this exposed portion of the Trough are dominated by a system of parallel east-west faults.

The oldest formation, consisting of metamorphic rocks and igneous intrusives, is found between Guantanamo Bay and the eastern end of the Island. Resting unconformably on this basal complex are the stratified rocks, partly Cretaceous, perhaps, but chiefly Eocene and Oligocene.

The Tertiary rocks extend westward to the end of the Sierra Maestra in the vicinity of Cabo Cruz, and, with minor exceptions, northerly dips prevail, so that in passing inland from the coast younger beds are successively encountered. Near Guantanamo Bay the stratified rocks are mostly, if not entirely, sedimentary in origin. Farther west there is a great series of explosion-breccias, and volcanic tuffs with some interbedded limestones and lava-flows, but near the top of the series, limestones and shales are encountered that are similar to those found north of Guantanamo. In the Santiago area the breccias are largely composed of fragments of andesitic rocks, but near the western end of the range they consist almost entirely of limestone fragments. Near the crest of the Sierra Maestra north of Pílon explosion-breccias are exposed that contain fragments of older breccia. Lava-flows are surprisingly scarce considering the large quantity of fragmental volcanic rocks.

The stratified rocks are cut by many dioritic and andesitic intrusives, which appear to be differentiates from a batholith of granodiorite that is exposed along the coast for 100 miles or more. The youngest intrusions are of basalt.

In the Santiago embayment and in the area north of the Sierra Maestra near Media Luna and Manzanillo, Miocene marls and limestones rest on the eroded surface of the older rocks.

The present topography of the Sierra Maestra is due to uplift along east-west faults, in most cases accompanied by northward tilting. The coast line is determined by these faults and the principal irregularities along it are due to the overlapping of parallel faults arranged en echelon.

Immediately east of Pilón the straight east-west shore line coincides with the mountain front. At Pilón, the mountain range continues its westerly course for about 12 miles before dying out, while the shore-line curves southward to form the shallow harbor of Rosenado de Mora, and then turns westward again along a line that is parallel to the mountain scarp, five miles away. The Plain of Pilón, lying between the two lines, rises gradually toward the west.

The uplift of the plain is recent, for along the coast terraced cliffs are cut into a modern coral limestone. The faulting along the mountain front began in Pliocene time, perhaps, but the movements have continued down to the present; for there has been some displacement of modern alluvial deposits along the inner margin of the plain. The terraces along the coast increase in elevation toward the west and reach a maximum of about 700 feet near Punta Escalereta, after which the elevation descends toward Cabo Cruz where low terraces curve northward before dropping to sea-level. Additional evidence of northward tilting is furnished by the recent rejuvenation of the streams that drain north and northwest from the crest of the divide.

Between Santiago Bay and the mouth of the Rio Bacanao, thirty miles to the east, there are three offsets in the coast line and each stretch of east-west coast is marked by a range of hills, a few hundred feet in height. The hills are separated from the mountains by a broad valley running parallel to the coast, and they are usually separated from one another by narrow gorges. The hills were formed by uplift along faults in late Pleistocene time and then were submerged by rise of sea-level at the close of the Pleistocene. Uplift of the land in Recent time has again exposed the hills.

Near Santiago Bay, the hills are formed of Miocene marl; farther east they consist of granite. They are partly covered with modern limestone formed during the submergence, but this rock has been removed in places along the coast by wave-action, and it is thin or entirely absent on the north slopes.

Near Santiago the uplift has not been sufficient to drain the bay but farther east, where the uplift has been greater, bays are absent, although small lakes are found back of the hills in the valleys of some of the streams that cut through to the sea. Between Santiago and Pilón coastal terraces and uplifted coral reefs are absent for long distances.

Several ridges located north of the main coastal ridge have been formed by faulting and the northward tilting of crustal blocks in Pleistocene and Recent time. The Sierra de Boniato and the Puerto Pelado, north of Santiago, were formed in this way, and the fault-scarps of these ridges intersect the strike of the rock strata at a small angle.

Near Cabo Maisí the recent uplift has been accompanied by very little tilting, so that the terraces continue around the eastern end of the island to the north coast with little decrease in elevation. This fact together with other evidence indicates that the uplift of the south coast of Cuba in Recent time has been due to forces acting in a vertical rather than a horizontal direction.

The uplift of the Sierra Maestra has been very irregular, for in some localities the terraces and cliffs with sea-out caves are perfectly preserved, while elsewhere they have been almost completely obliterated by erosion. Moreover, the terraces instead of being uniform in elevation, rise and fall within relatively short distances. The earthquakes of the region are due to the faulting that is now going on and, during the last four centuries, seismic activity has been greater near Santiago than elsewhere along the south coast of Cuba.

Some of the north-dipping strata in the Sierra Maestra, such as the coral limestones and the conglomerates, must have been formed in shallow water. The deep

Bartlett Trough has therefore been formed by down-faulting rather than by the uplift of the sides, although both processes seem to have been going forward simultaneously.

University of South Carolina,
Columbia, South Carolina

SEISMIC ZONES AS RELATED TO RELIEF OF OCEAN-BOTTOM

N. H. Heck

The significance of the earthquake in relation to the study of oceanic areas by geophysical methods lies in the fact that beneath the sea, as well as on land, the earthquake gives evidence that forces are at work which are either missing or inactive in other regions. The earthquake, therefore, can serve the investigator by pointing out the places where his efforts are likely to be especially productive of results.

In the study of regions subject to earthquakes, the first obvious step is to see whether they possess some special peculiarity not shared by other regions. In considering the ocean-basins and adjacent coastal regions and islands, the first thing to consider is the topographic relief, since if coordination is established it should prove helpful in solving the problems. Submarine relief beneath the sea is not more significant than that on the land, but is likely to be more helpful, since it is more sharply defined as weathering processes causing a change are not active.

A casual examination of the great earthquake-belts of the Earth (Fig. 1) brings out the fact that for a great part of their length, especially of the Pacific belt, earthquakes are associated definitely with mountain chains especially those the least worn down; with equivalent island chains; and with deep ocean-troughs which parallel these features. In general, the sea-basins (with some definite exceptions) which do not possess these characteristics have relatively few earthquakes. The most important exception is the region of the mid-Atlantic ridge which, with a moderate elevation above the region on both sides and itself for the most part deeply submerged, still has numerous earthquakes, though not perhaps of the first order of intensity.

My subject is the relation between earthquake occurrence and submarine relief. I must begin by stating that for much of the Earth the relation can be established only in a very general way. This is for the reason that accurate facts regarding both the position of earthquake-epicenters and the bottom-topography must be known in detail. This is true at the present time only for small portions of the earthquake-belts.

Accurate knowledge of earthquake-epicenters, a purely seismological problem, is dependent on many elements. These include: The existence or nonexistence of seismological stations reasonably near the epicenter; sensitivity of the seismographs; type of record, depending partly on apparatus and partly on type of arriving earthquake-waves; accuracy of time on the record which depends both on uniformity of rotation of the recording-drum and on knowledge of the absolute time through radio reception of time-signals; correctness of curves and tables giving travel-time of earthquake-waves with the arrival time of the various so-called phases; travel-times in local surface-layers and thickness of these layers under the ocean; and the depth of origin of the earthquakes.

Under especially favorable conditions in California, earthquake-epicenters are located instrumentally within less than one mile. In the Dutch East Indies the accuracy has been high. However, from such conditions there is a wide range to conditions represented by parts of the north Pacific Ocean, especially the wide basin between the Aleutian and the Hawaiian Islands chains. If we record all the epicenters given in the International Seismological Summary and its predecessors, we find a wider scattering in the region of the Aleutians than seems probable.

Equally uncertain is the determination of submarine relief. For example, in the case of the Dutch East Indies, though many additional soundings would not come amiss, the bottom-topography is fairly well known. In the Aleutian region, while we are able to infer the existence of a great trough paralleling the Alaskan peninsula and the

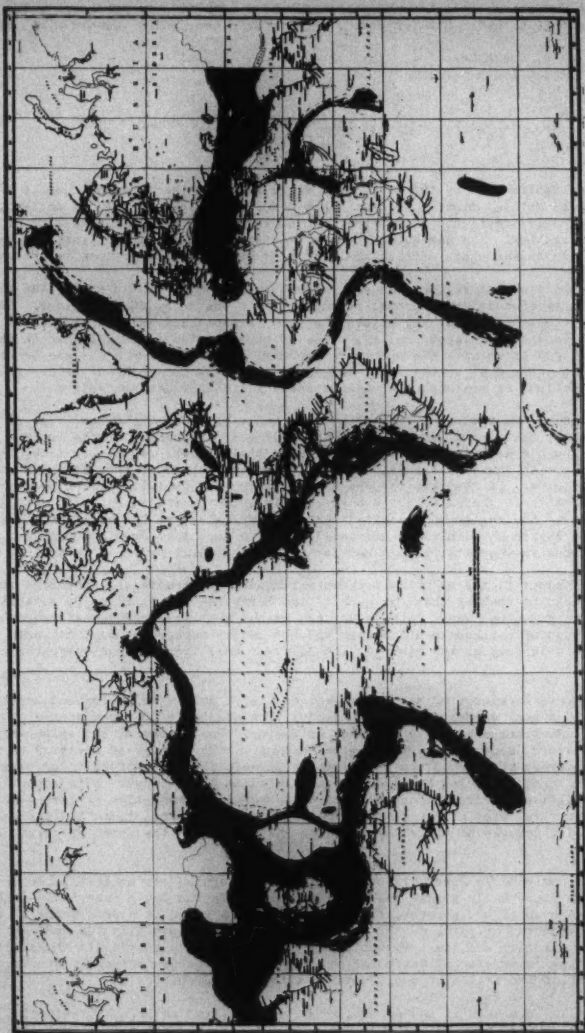


Fig. 1--Earthquake-belts of the Earth

Aleutian group which extends at least 2,000 miles to Kamchatka, we have but 15 poorly spaced soundings to prove its existence and none that give its width or contours.

The handicap imposed by this lack of information is obvious by comparing the situation in the Dutch East Indies. The work of Meiness, Visser, and others, supplemented by a considerable amount of surveying work by the Netherlands Government, has brought out the relation between the belt of gravity-anomalies, the contours of the ocean troughs, and earthquakes (Fig. 2). It is shown that the belt of negative anomalies does not, in general, coincide with the troughs but lies on the inshore side. However, the evidence is that the belt of negative anomalies could almost be arrived at for part of its length by drawing the best adjusted line of maximum earthquake-activity; that is, with the activity on both sides of the line evenly balanced.

It is impossible to discuss this problem for the entire Earth. I, therefore, selected three regions which cover practically the whole range of association of submarine relief with earthquake-occurrence. It is, of course, impossible to go into full detail even with regard to these, but I hope to bring out the salient facts. The regions selected are the Bahama-Caribbean; the mid-Atlantic region; and the Aleutian region. We can readily conceive of expeditions to undertake further investigations in each of these regions so that the assembling of the facts should not only be illustrative but of future use.

The Caribbean Sea has a number of features of unusual interest (Fig. 3). It is associated with the feature from which the Atlantic Ocean is usually free, the great submarine troughs. One of these, the Mares Deep, has the greatest depth in the Atlantic and the Bartlett Deep has depths considerably greater than those on either side. Whether it is significant or not, the axes of these troughs lie in practically the same straight line even though the Island of Haiti separates them. It is also of interest that in this general region the most westerly extension of the Atlantic ridge occurs though it is 900 miles to the east. There is reason to suspect smaller deeps east of the Windward Islands though no soundings have been taken which either prove or disprove their existence.

Another feature of unusual interest is earthquake-activity. Montessus de Ballore, who made the first world-wide appraisal of earthquake-activity, considered that the main part of the Pacific belt, instead of following the Isthmus of Panama and through Central America through Guatemala, actually followed the south, east, and north sides of the Caribbean Sea to Cuba, thence along the Bartlett Deep to Honduras and Guatemala. However, there is considerable activity along the other line so that

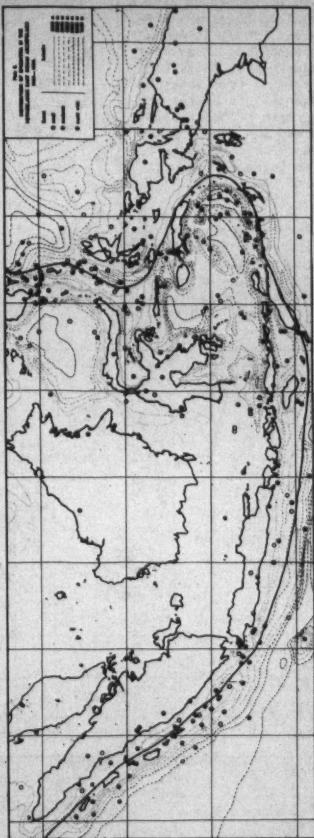


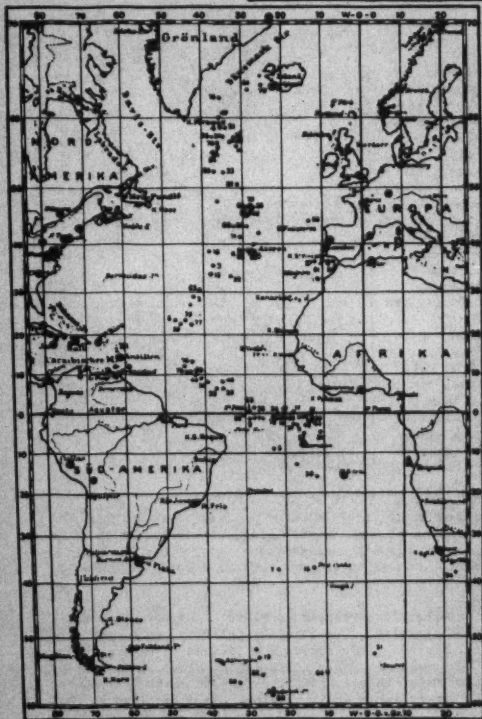
Fig. 2--Belt negative gravity-anomalies and earthquake-epicenters, Dutch East Indies, after Visser and Meiness

so that we appear to have a closed loop of earthquake-activity. There is one other such loop in a major earthquake-belt (Fig. 5). This extends from Japan to New Guinea, one branch following east of the Philippines and the other by way of Guam. It is important that we learn the significance of these closed loops.

The recent work of the Princeton-Navy Expedition made an invaluable addition to our knowledge of the more critical part of the Caribbean area. There is



Fig. 3--Earthquake epicenters, Caribbean Sea



need for more seismograph-stations in order to determine the position of earthquakes with the required accuracy. At present there are three modern installations: That at the Coast and Geodetic Survey observatory in Porto Rico; that of the Carnegie Institution of Washington at the magnetic observatory at Huancayo, Peru, not in the region but near enough to give very valuable records. In the Isthmus of Panama seismometers for recording nearby earthquakes are being installed, and these instruments frequently give good records of more distant earthquakes.

There is no use considering at the present time the best possible combination of stations, but there is special need for the modernization of the stations at Havana, Kingston (Jamaica), Port au Prince (Haiti), and Martinique. There is particular need for two other stations, namely, one in the Bahamas, probably at Nassau, and one on the north coast of South

Fig. 4--Earthquakes Mid-Atlantic Ridge after Tams, recent epicenters added

America, preferably at Curacao. Several of these stations would also be useful in connection with the study of the Atlantic Ridge. In connection with the study of vertical movements, it would be desirable to set up tiltmeters at such a place as the south coast of Cuba, as proposed by Dr. Merritt before the Section of Seismology, and it should be the aim for the future to install a number of Wood-Anderson short-period seismographs on both sides of the Bartlett Deep as Professor Taber has suggested.

An oceanic region of great importance is the Mid-Atlantic Ridge (Fig. 4). Anyone interested will find much accumulated information in the paper of Washington on the Origin of the Mid-Atlantic Ridge. It is possible to state from existing information that the ridge extends from Iceland to the Antarctic, roughly paralleling the coast to east and west. It has depths of 2,000 fathoms or less with some islands, and, in general, it projects 3,000 to 6,000 feet above the ocean-floor on both sides with a few peaks rising 18,000 to 20,000 feet. It is of especial interest to note that nowhere did there appear to be a trough on either side. Should a belt of positive gravity-anomalies be expected here? Figure 4 shows the comprehensive earthquake-information for this region. It is significant, as Washington points out, that St. Paul Rocks are of different formation from any known oceanic island and are highly metamorphosed. The great need is for more accurate determination of earthquake-epicenters.

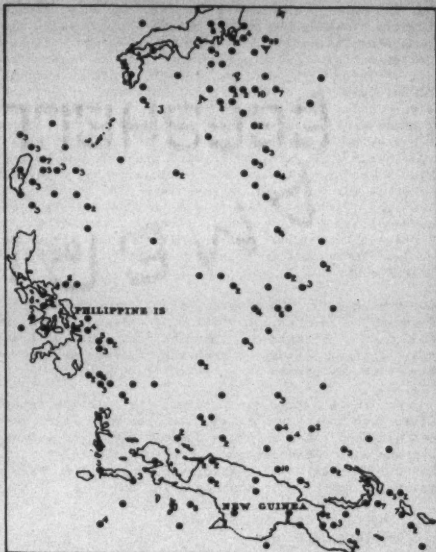


Fig. 5--Earthquake-epicenters, Japan to New Guinea

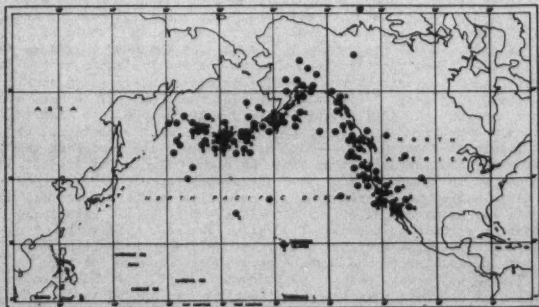


Fig. 6--Earthquake-epicenters, northeast Pacific

The work of the Meteor has resulted in some excellent sections across the south Atlantic crossing the Ridge, but to obtain needed information an expedition would have to confine its entire attention to the ridge. It is hard to find sufficient suitable station-sites. However, existing stations in Europe, the Azores, Iceland, Greenland, east coast of North America, the West Indies, and the east coast of South America, are all helpful. The stations which have been proposed for the Caribbean region would all be very helpful, especially those in the eastern part. A station at Bermuda would be of great assistance and there should be modern instruments on a good operating basis at a station on St. Helena and the Ascension Islands. The Aleutian region study is a major project (Fig. 6) which will probably not be reached for a long time. Nearly all that is necessary to say has previously been said, but I am including this region to emphasize the fact that we have large areas practically untouched. In the case of the Aleutians, surveys of the islands themselves are needed in order to provide the needed shore-control for hydrographic surveys, including that of the deep trough to the south. At present the nearest teleseismic stations are those at Sitka in Alaska, Victoria in Canada, Vladivostok in Siberia, and Tokyo and Kobe in Japan. These are all useful but too far away.

Expansion of the program, additional instruments, and scientific personnel will be necessary so that the volcanological stations at Dutch Harbor and Kodiak Island would make a satisfactory contribution. Both of these sites, however, have important possibilities. It may be necessary to have at least two additional stations in the islands if the region is to be adequately studied.

Pending the time, perhaps put far into the future by present-day economic conditions, when such investigations can be made in an adequate manner, it can be stated that earthquake-belts follow definite types of surface-features. Undoubtedly, since both are due to the same cause, there is a relation. The outstanding problem is to find out whether it is possible to deduce from these and other relations a satisfactory explanation of what is going on.

U. S. Coast and Geodetic Survey,
Washington, D. C.

INTERPRETATION OF GRAVITY-ANOMALIES AND SOUNDING-PROFILES OBTAINED IN THE WEST INDIES BY THE INTERNATIONAL EXPEDITION TO THE WEST INDIES IN 1952

Harry Hammond Hess

The work recently completed in the West Indies was dependent on Dr. Meiness's previous important discoveries in the Dutch East Indies. There he found a narrow band of strong negative anomalies, about 100 miles wide and 5,000 miles long, extending along the southwest side of Sumatra and Java, then crossing northward east of the Philippines. The band is bordered on either side by bands of positive anomalies. The negative strip does not show a direct relation to topography. It is not located over the axis of the deep, though frequently it lies beside the deep. In some cases it crosses the islands themselves. It does show an indirect relation to the major topographic features to the extent that it parallels the island-arcs and usually lies near the steeper side of the deep. If such features as the long, narrow Java or Philippine deeps were not compensated isostatically, then one might expect to find negative anomalies immediately over them as a result of the lack of mass represented by the deep. Such a relationship does not exist, as pointed out above. The fact that the negative strip is narrow and distinct indicates that the disturbing factor producing it cannot be very deep-seated in the Earth's crust. The deeper the disturbing feature is, the more widely distributed will be the field of anomalies at the surface and the smaller will become the actual magnitude of the anomalies. A rough estimate shows that the disturbing feature extends to a depth of 40 miles or less. The strip of negative anomalies has been interpreted by Dr. Meiness to be the result of the downward buckling, crumpling, or folding of the lighter upper crust beneath the zone outlined by the anomalies. (This upper crust, perhaps 15 kilometers thick, may be estimated to have a specific gravity of 0.3 less than the material below it. Assuming such a difference in density, an anomaly of -120 milligals might result from the lighter mass under the station having dimensions of the order of magnitude 60 kilometers deep and 40 kilometers wide.) The lack of a direct relation of the negative strip to topography is ex-

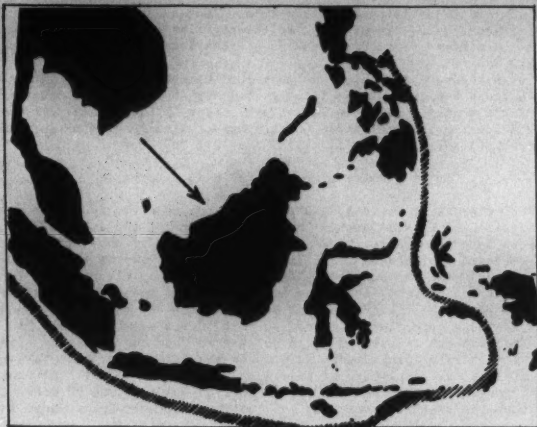


Fig. 1--The East Indies, hatched line indicating strip of negative anomalies and arrow approximate direction of maximum compression

plained by Dr. Meiness as follows: A thin upper layer a few miles thick does not partake of this downward folding, but folds or wrinkles upward as the underlying crust slides beneath it. With more intense deformation, overthrust-sheets may be developed in this surface-layer. In this manner the trough situated over the major downfold may be wholly or partially filled by the surface-material. If the trough is not completely filled, it remains as an ocean-deep. This deep will be situated toward the ocean-side of the former greater trough, the side nearer the islands being more completely filled by the material of the surface-folds or thrusts; this explains the fact that the strip of negative anomalies usually is located beside, rather than immediately over, the present deeps. It has been found that the line of earthquake-centers correlates well with the strip of negative anomalies, giving further evidence that it

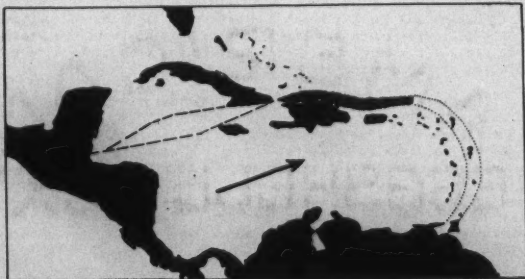


Fig. 2--The West Indies, hatched line indicating strip of strong negative anomalies and arrow approximate direction of maximum compression

represents a line of major tectonic disturbance. Another interesting feature is the occurrence of volcanoes in arcs parallel to the negative strip distant about 100 miles and always on the concave side of the curves of that strip.

The above is a very much condensed summary of Meiness's ideas as interpreted by the writer. Because the subject has been treated very briefly and because certain conceptions of the writer's may have unwittingly crept in, he wishes to refer the reader to Dr. Meiness's original paper (F. A. Vening Meiness, Gravity-anomalies in the East Indian Archipelago, R. Geog. J., v. 77, 323-337, 1931).

Brief summary of results of S-48 expedition

On the S-21 expedition in 1928, a strip of strong negative anomalies was found north of Porto Rico and Haiti. One of the major objects of the expedition on the S-48 this year was to determine where the westward continuation of this strip was located. Did it swing westward over the Bartlett Trough; did it follow the trend of Cuba; or did it bend northwestward through the Bahamas? A broad loop was run from Guantanamo Bay, near the east end of Cuba, southwest around Jamaica, thence northwest around the west end of Cuba to Key West and then back to Guantanamo via the Bahama Channel north of Cuba. The stations were closely placed so that if the negative strip had entered the "bag" at the east end of Cuba it could not emerge from the west side (from Jamaica to Key West) without being picked up. As soon as the first rough computation of the results were made at the completion of this loop, it became apparent that the negative strip did not emerge from the "bag." Further work at the east end of Cuba and to the north proved that the negative strip did not continue farther, but stopped there rather abruptly.

Over the eastern end of the Bartlett Trough sonic sounding depth-profiles, as well as the gravity-results, indicate that its floor is probably made up of a jumble of tilted, faulted blocks. The gravity-anomalies show no particular arrangement. They are never very large and may be either positive or negative, up to 57 milligals. The Bartlett Trough between the west end of Jamaica and the west end of Cuba seems to have a smoother floor. The anomalies over this region are all positive (ranging from +37 to +86) with one exception, namely, the station near Grand Cayman Island with an anomaly of -1. The north side of the Trough just south of Grand Cayman is a very steep slope.

Of 37 gravity-stations in the Bahama region, 35 are negative, and two located in the extreme northwest corner are positive. The largest value is -58 milligals, but most of the stations are about -20 milligals, which is a comparatively small anomaly. As yet no definite conclusion has been made as to the cause of this broad negative field. It is significant that so large a block should be uniformly negative and perhaps points toward the fact that the block acts as a unit.

The Gulf of Mexico and the Caribbean Sea both seem to be broad positive fields from all the data collected to date. Though several explanations are possible to account for these fields, further gravity-work on such features must be done before a definite conclusion can be arrived at.

Regional relations and origin of the Bartlett Trough

Unlike other deeps, thus far investigated in the East and the West Indies, the Bartlett Trough does not seem to be associated with a negative strip, or, in other words, is not over a down-fold. It is apparently a down-faulted region. In places it has been broken up into a large number of small blocks, and the whole aggregate of blocks has been dropped down. This seems to be the case near its eastern end. In other places it seems to have been broken into fewer blocks, or may even be a single large block which has been dropped down. Recent block-faulting has taken place all along the southern coast of eastern Cuba which forms the northern margin of the Trough.

This normal faulting probably indicates that the area outlined by the Trough's boundaries has been recently under tensional stress. At first glance, this seems to be at variance with the facts obtained elsewhere in the West Indies. The negative strip north of Haiti and Porto Rico points toward strong compression in the Caribbean, especially if (drawing the analogy to the East Indies) it is supposed that the negative strip continues, paralleling the island-arc of the Lesser Antilles, to the coast

of South America. From there it might well extend eastward following the trend of the ridges in Venezuela and joining the Andes in Colombia. Preliminary reports from the Mexican government indicate that a strip of negative anomalies cross Mexico in an east-west direction opposite the western tip of the Bartlett Trough. Meinesz's work on the Dutch submarine K-XIII showed that this negative strip apparently swings northward, following the Pacific coast.

Considering the broader structural relations, we find a long north-south system of Tertiary mountains from Alaska to southern Mexico, and from Colombia to Cape Horn. From southern Mexico to Colombia, however, the line of deformation makes a great jog eastward and probably follows the trend of the Lesser Antilles, as already suggested. In the whole mountain system, the major compression has been in an east-west direction. The negative strip, or postulated down-fold resulting from this compression, has been found in southern Mexico, is absent for the length of the Bartlett Trough, and reappears again at the east end of Cuba.

It is here suggested that the Bartlett Trough is a direct result of the shearing of the Caribbean block from the block to the north of it. As the Caribbean block moved eastward, causing a line of deformation along its eastern margin, it tore away from the block to the north, possibly along lines represented by the northern and southern margins of the present Trough. The Trough itself has an east-west direction; thus it is nearly parallel to the direction of compression, and it serves as the connecting link between the two lines of compression.

The earthquake of February 3, 1932, which did so much damage at Santiago, Cuba, may well have been the result of horizontal movement along such a shear-zone parallel to the northern edge of the Bartlett Trough. The opening of a fissure on Pico Turquino, the city of Santiago, and the point off the east end of Cuba where a small tidal wave was reported to have occurred at the time of the quake, all lie along a line parallel to the margin of the Trough.

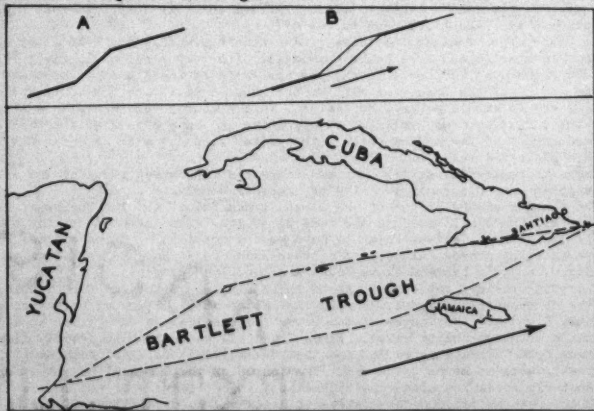


Fig. 3--Cross marked on map west of Santiago is Pico Turquino where fissure opened during earthquake; cross in Windward Passage just east of Cuba is where ship reported a tidal wave at time of quake

If the line of shearing were not quite parallel to the direction of compression either tension or compression would result along it. For example, if a portion of the line of shear bent 10° farther toward the southeast, then the eastward movement of the Caribbean block would result in the pressing together of the walls of the shear. If, however, a portion of the line of shear bent 10° farther toward the northeast, then eastward movement of the Caribbean block would result in the tearing apart of the walls

of the shear. Such a situation is portrayed diagrammatically in A and B of Figure 3. In the diagram the walls have actually been moved apart leaving a void. In the case of the Bartlett Trough this, of course, did not happen, but as a result of similar circumstances the area included in the Trough has been relieved of compression thus allowing the extensive block-faulting of the region.

An explanation for the sinking of the block-faulted area to form the Trough may lie in the fact that, when it was formerly under compression, it was held up to a certain extent by the vertical component of the compressive forces acting on a slightly arched region. Now that the compression no longer exists on the area, this support has been removed and the area has sunk back toward equilibrium for the new conditions.

Submarine valleys in the Bahamas

In the Bahamas the sonic sounding-profiles were of more interest perhaps than the gravity-observations. An attempt was made to determine the origin of such features as the Tongue of the Ocean, Exuma Sound, and Northeast and Northwest Providence Channels. They form deep indentations in the Bahama block which, for the most part, consists of shallow water (up to 100 fathoms deep) and occasional islands.

A sketch map based on the soundings with a contour interval of 250 fathoms is given in Figure 4. The contours are reasonably accurate for the lower part of Northwest Providence and Northeast Providence Channels, as well as for the mouth of the Tongue of the Ocean. The rest, however, has been sketched in from relatively few soundings. These submarine valleys have the following characteristics:

- (1) They slope continuously seaward from their shallowest point to the place where they join the ocean-basin proper at about 14,000 feet below sea-level.
- (2) Where two of them meet, they meet at the same level or "at grade," and where they enter the ocean-basin proper they enter at the same level.
- (3) They have pronounced V-shaped cross-profiles in their lower reaches, with gradients of about 100 feet to the mile.
- (4) In their upper reaches they have gently sloping, undulating bottoms at about 800 fathoms (4,800 feet below sea-level) with very steep walls rising from 500 fathoms (3,000 feet) to the surface, with at least a 35° slope.
- (5) The Tongue of the Ocean, as well as the unnamed valley to the southeast of it, end in amphitheater-like basins. This feature, together with a steep-sided, flat-bottomed valley, is suggestive in shape of a glaciated valley and cirque of tremendous size. (The writer does not wish to infer that they are glaciated valleys.)
- (6) There is some evidence from the soundings that the steep sides of the valleys approach the floors in a series of steps or benches.
- (7) The courses of the Tongue of the Ocean, Exuma Sound, and the Northwest Providence Channel all trend in the same direction. The direction of the course of these three valleys seems to have been controlled by three ridges, one paralleling Andros Island, one between Exuma Sound and the Tongue of the Ocean, and one between Exuma Sound and the ocean proper.
- (8) Where the valleys cut across one of these ridges, as they do for example in the Northeast Providence Channel, they do so at right-angles to the ridge.
- (9) Exuma Sound and the Tongue of the Ocean lie parallel to each other at a distance of about thirty miles. Exuma Sound slopes in a southeasterly direction from 750 fathoms (4,500 feet below sea-level) to 2,250 fathoms (13,500 feet) where it meets the ocean. The Tongue of the Ocean slopes in a northwesterly direction also from 750 fathoms (4,500 feet) near its source to 2,300 fathoms (13,800 feet) where it meets the deep-sea floor of the Atlantic (after joining the Northeast Providence Channel).
- (10) There are two or three rather distinct changes in gradient in the longitudinal profile of the Northwest Providence Channel and probably corresponding ones in the lower part of the Tongue of the Ocean.

From the data presented above, one conclusion seems inescapable--that the so-called valleys are actually drowned erosional features and not the result of any diastrophic movements. Little doubt can be entertained that at least the lower reaches of these valleys were cut by stream-erosion. The nature of their longitudinal and transverse profiles, the fact that tributaries meet the river "at grade," and the

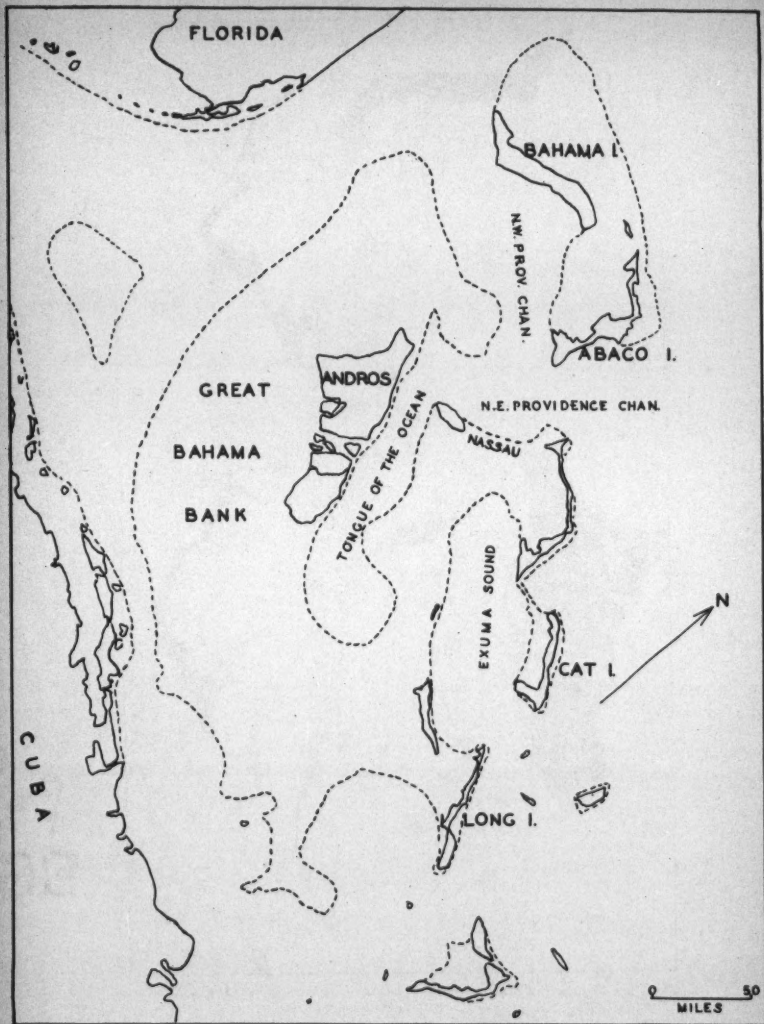


Fig. 4--Key-map of the Bahama area

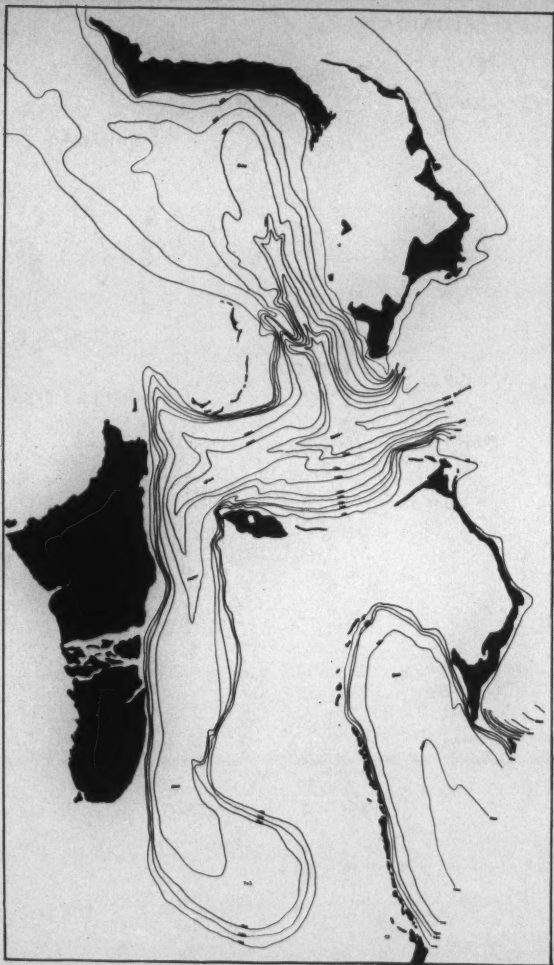


Fig. 5--Contour-map of submarine valleys in the Bahamas giving 100-, 250-, 500-, ----, 2,250-fathom contours

evidence of periodic rejuvenation appearing at corresponding levels in at least two of the valleys, are all characteristic of river erosion, and could not have been formed by any conceivable sequence of coincidences by another process or processes. J. W. Spencer (Reconstruction of the Antillean continent, Bull. G. S. A., v. 6,

103-140, 1895) recognized them as submerged river-valleys as early as 1695. These valleys before submergence must have been majestic features. The Northeast Providence Channel was 30 miles wide and 14,000 feet deep where it entered the ocean, or three times the size of the Grand Canyon.

Further study will be necessary before certain secondary features of these valleys can be explained. As yet no satisfactory conclusion has been arrived at for the shape of a valley such as the Tongue of the Ocean in its upper reaches with its steep sides, flat bottom, and cirque-like termination. This does not, however, invalidate the conclusion offered for the valley system as a whole.

The control of the valley by three parallel ridges and the fact that where the valleys cross the ridges they do so at right-angles, points strongly toward certain analogous features in the Appalachian Mountains. In the Appalachians a drainage was developed on a peneplained or truncated series of folded sedimentary rocks. Since some strata were much more resistant to erosion than others, differential erosion resulted in long parallel ridges supported by the more resistant rocks and the intervening valleys were developed in the less resistant ones. Where a river cut through a hard ridge, it did so at right-angles to the ridge. It may be that a similar sequence of events has taken place in the region of the Bahamas. The present flat areas at shallow depths and the islands are remnants of an old peneplained surface on folded rocks. It was into this surface that the valleys were incised when it stood as a high plateau thousands of feet above sea-level. Perhaps the levelness of the former plateau has been accentuated by accumulation of reef-material on top of it.

The material presented in this paper may be considered as a preliminary report on the data collected by Dr. Meinesz, T. T. Brown of the Naval Research Laboratory, and the writer while on the International Expedition to the West Indies and the conclusions are tentative. Not all of the gravity-stations have as yet been computed and a further consideration of the various problems may lead to changes in some of the ideas presented.

The interpretations of the data have been made by Dr. Meinesz and the writer without the benefit of the opinions of the members of the various committees related to the Expedition, some of whom may have other interpretations than here presented.

Princeton University,
Princeton, New Jersey

SOUNDING THE DEPTHS OF THE OCEAN FOR MAPPING THE CONFORMATION AND TOPOGRAPHY OF THE BOTTOM

G. W. Littlehales

The unceasing stream of deep-sea soundings from national and institutional vessels of countries bordering or having interest in the ocean, among which those of the United States have made a large contribution, is year by year advancing to a nearer stage of realization the once distant prospect of mapping the conformation and topography of the bottom of the ocean.

I will not ask you to ascend the steps by which the present stage of progress has been reached, but, in association with my endeavor to convey to you an impression of the accumulations that have been gathered, I would have it recalled that in the middle of the nineteenth century--which marked the close of the period of coast reconnaissance and island discovery following the period of circumnavigation and continent discovery--the sea remained unfathomed, excepting in the shallower waters bordering the land where there were in progress, as national undertakings in aid of commerce and navigation, those marine hydrographic surveys which have eventually made the coastline of the world the best known of the major geographical features of the world. In that unfathomed state, while the former and present role of the ocean, in the history of the Earth and its economy, did not go unnoticed, oceanography had not yet forged those bonds of kinship which now relate it to many other branches of science, and which augment its impetus.

Progress had necessarily been gradual in the bathymetry of the ocean, because of its immensity in extent and the difficulties which have beset such measurements. A sounding is not an affair of one dimension: Such a measurement applies to a particular place and to define that place on the surface of the Globe requires the determination of two additional dimensions.

All measurements of the depth, by which the configuration of that part of the Earth's crust covered by the ocean is ascertained, are referred to the sea-surface, which is an equipotential surface, warped by undulations weaving in and out by unknown amounts below and above the surface of the theoretical spheroid, in consequence of the attraction upon the hydrosphere of the heterogeneous and elevated portions of the lithosphere as well as the uneven distribution of the weight of the atmosphere and the varying intensity of the forces of Nature. Nevertheless, it is not regarded as likely that the surface of the geoid departs so widely from the mean ellipsoidal form as to invalidate its use in estimates of the elevation and depression of the bottom of the ocean.

Sensible of the national advantages to be gained by supplying American ships with information respecting those waters through which their voyages might be directed, the Congress of the United States, by statute, established for this purpose the United States Hydrographic Office. This Institution produces and issues in successive editions more than 3,000 different publications relating to the ocean, including charts ranging in continuous succession throughout its entire expanse--an expanse exceeding by eighty million square miles the total area of all the lands of the Globe.

In former times, the charts were encumbered with representations of reports of doubtful dangers that had come down from former generations of navigators. To furnish evidence, by measuring the depth of the ocean, that would verify or disprove these reports, often doubtless based upon misleading appearances of the surface of the sea, required that the depths of the ocean should be sounded, and the charts of the Hydrographic Office have thus become, by natural development, the repository of the accumulated facts of observation which lend themselves to the delineation of isobathic contours.

In former communications to the American Geophysical Union, I have referred to the bathymetrical chart of the Hydrographic Office, but today I have brought the sheets of the Monaco Carte Générale Bathymétrique des Océans because the soundings that are registered upon them have been counted, and it is the result of this count that I wish to relate in order to convey the impression that, while the state of knowledge which is necessary for the analysis of details has not yet been attained, oceanographers have been diligent in the careful consideration of the accumulations of soundings, but have been obliged to confine themselves to attempts to delineate those broad features of the general orography of the ocean-basins concerning which alone conclusions may at present be reached.

The total number of soundings greater than 1,000 meters in depth registered in these sheets is 14,900. Of these 6,100 are in the Atlantic Ocean, 2,500 in the Indian Ocean, and 6,300 in the Pacific Ocean. If they were evenly distributed throughout the several basins, there would be in the Atlantic one sounding to each area of 5,367 square miles, in the Indian one sounding to each area of 10,736 square miles, and in the Pacific one sounding to each 10,039 square miles. There are regions of the ocean as large as the continental United States where not a single authentic sounding is recorded.

While it must be remembered that not all the known soundings could be entered in some part of these chart-sheets, yet where none is laid down, none has ever been measured; and in regions where soundings are represented, if all the reported soundings could be included instead of the selection which is given where the room does not allow more to be shown, there would yet be too few, in general, to serve for the delineation of the details of the contours of configuration of the bottom of the ocean. Nevertheless, there are some parts of the ocean where the number and distribution of the measurements have proved sufficient to afford an approach toward a fulfilment of this purpose, notably in the South Atlantic Ocean since the expedition of the German steamer Meteor and in the lane extending from California to Hawaii, of which a contoured map and profiles are published in United States Executive Document No. 153,

Fifty-second Congress, First Session, being the "Report of the results of the survey for the purpose of determining the practicability of laying a telegraphic cable between the United States and the Hawaiian Islands." And, recently, the method of measuring the depth of the ocean by means of the sonic depth-finder has been employed in the survey of a tract of the bottom of the Pacific Ocean 34,000 square miles in extent, bordering the coast from San Francisco to San Diego and extending seaward to the depth of 2,000 fathoms. A map of the topography of the ocean-floor resulting from this survey by two vessels of the Navy in the course of 34 days has been published. This map was of great significance to the Advisory Committee in Seismology because it seemed to indicate that the mapping of the oceanic basins had been brought within the range of feasibility.

In the present edition of the Carte Bathymetrique the geographical position of each sounding is shown and the isobathic contours are delineated for each interval of 1,000 meters beneath the surface of the ocean, and, besides these, isobaths are supplied at 200 and 500 meters. The areas between these contours on the charts are tinted blue in shades that become deeper with the depth of the water. The number of shades of blue thus reaches twelve.

The areas enclosed between the successive isobathic contours are now estimated as in Table 1.

Table 1--Estimated areas enclosed between successive isobathic contours

Contour		Area enclosed	
From	To		
m	m	million sq. km	per cent
0	200	30.60	8.4
200	1000	16.40	4.4
1000	2000	18.05	4.9
2000	3000	36.45	9.9
3000	4000	79.01	21.7
4000	5000	112.72	30.8
5000	6000	66.88	18.4
Beyond 6000		5.38	1.5

By these results, it appears that about one-half of the sea-bottom lies at a depth exceeding 4,000 meters. A study of the distribution of these greater depths below 4,000 meters, below 5,000 meters, and below 6,000 meters, in successive 10° zones of latitude, has shown that, whereas the greatest expanse of ocean lies in the southern hemisphere, the areas of the floor of the ocean deeper than these successive isobathic contours are greatest in the northern hemisphere between the parallels of 10° and 40° of latitude, in the same planetary zone in which epirogeny has attained its greatest manifestation in the continents. It is interesting to note that the area of less depth than 200 meters amounts to 30.60 million square kilometers, whereas the area occupied by the fourfold interval next succeeding, from 200 to 1,000 meters, amounts only to 16.40 million square kilometers. Thus, in proceeding oceanward from the coast, the descent from the emergent tracts into the ocean is marked in its earliest stages by one of the great, world-wide characteristics of submarine topography, consisting of a bordering platform dipping gradually under the sea to a boundary which, while it has no sharp definition in point of slope and depth, is commonly, though somewhat arbitrarily, regarded as being marked by the depth-contour of 200 meters, although in fact the depth of the edge, as well as the width of the zone, varies much in different continental regions.

This is the continental shelf, and, as indicated by the foregoing measurements, it is adjoined by a zone of increased rate of descent, called the continental slope. Not only is the continental slope the seat of many deposit-slips and seismic disturbances, but evidence has been produced to show that underground rivers sometimes enter the ocean at depths beyond the 200-meter line and there bring about sudden changes in deep water. And, again, the continental shelf and the continental slope are occasion-

ally traversed by gully-like physiographic features, such as the Monterey Gully on the coast of California and those associated with the mouths of the Hudson and the Congo, and other great rivers. The relatively diminishing areas which lie beneath increasing depths reveal the presence of the maximum gradient of this slope between 200 and 2,000 meters, and, in like manner, the increased areas which lie beneath the succeeding deeper zones mark the transition, between 2,000 and 3,000 meters, to the markedly lessened gradient which characterizes the course of descent prevailing thence throughout the depths ranging down to 5,500 meters.

In order to convey an impression of these gradients, a profile of the Pacific Ocean from California to the Hawaiian Islands has been constructed upon the same scale for the representation both of depths and of horizontal distances. From whatever part of the world they are obtained, such profiles do not support the view that the ocean-floor is in general devoid of features of relief. The present profile above mentioned is derived from a continuous line of homogeneous soundings taken less than 10 miles apart, on the average, and frequently at alternate intervals of 10 and 2 nautical miles, along the arc of a great circle of the Globe passing from Point Concepcion to Hilo. Although gentle gradients prevail, great mountainous formations are present in latitude 32° 20' and longitude 128° 03' and in latitude 27° 25' and longitude 140° 42', and many variations of relief thousands of feet in elevation. Indeed, the diversification found to characterize the tracts about which most has been learned points to the view that the oceanic basins are extensively featured with orographical formations. The details of the subject can not be approached with any real sense of satisfaction until knowledge by observation is extended to provide materials for the delineation of isobathic contours at much closer intervals than 1,000 meters.

By the side of these general deductions may be mentioned the indications ascertained by seeking for the greatest difference in depth in each quadrilateral tract bounded by parallels of latitude 2° apart and by meridians of longitude 2° apart. In the North Atlantic Ocean, between the parallels of 45° and 53° of latitude, changes of relief varying from 800 meters to 1,200 meters were disclosed by this plan of investigation, which points to that which is seen in the topography of the continents.

The gradient at which many islands rise from deep-sea bottom is very steep. At the island of St. Helena there are slopes of 38° 30' and 40°; at Tristan de Cunha 33° 30'; at St. Paul, in the Atlantic Ocean, 62° on a short stretch. These slopes were found in the upper 300 meters; at greater depths the slopes are more moderate. Thus at St. Thome in the Gulf of Guinea, between 1,750 and 2,530 meters depth, the slope is 15°, while in the upper parts twice as much has been found. The submarine base of Jan Mayen, on the east side between depths of 620 and 1,940 meters, has a slope of 6° 45' and thence to a depth of 2,330 meters, a slope of 4°. For the volcanic islands in the Mediterranean Sea, slopes of 15° to 22° are not uncommon. For the great Caldera of Santorin, the slope is over 50°. Molokai of the Hawaiian Islands, on the north side, has a slope of 6° 15' to a depth of 3,800 meters. In the case of non-volcanic islands, the slope is often smaller, especially the boggy islands of the Mediterranean Sea, whereas Cuba, at 75° west longitude, on the south coast, slopes to a depth of 2,625 at an angle of 35° 30'. In the case of coral islands, which often surround a volcanic core, the slope is also considerable. Thus, the base of the Bermuda Islands slopes down to a depth of 3,840 meters at an angle of 16° 30'. The Lucipara Islands in the Banda Sea have slopes which, at a distance of two km from the edge of the reef, average 34° 42', while 50' is reached between depths of 200 and 400 meters; at greater depths the slope is only 16° to 19°. To afford a comparison, it may be stated that Fujiyama in Japan, one of the finest specimens of a volcanic peak, has a slope of 35° at the steepest part, and at the base it is still 12° to 13°.

Steep slopes are occasionally found also on the bases of the continents where the area between the depth levels of 1,000, 2,000, and 3,000 meters is comparatively small. An example of this is the quick descent of the European continent into the depths of the Atlantic. Westward of the British, French, and Iberian coast-banks, an average angle of 15° to 14° has been found. Several isolated mountains stand separated from the coast-bank at the point where the French telegraph cable from Brest to New York reaches the deep sea on the north side of the Bay of Biscay, in 45° 30' north latitude; on the sides of these mountains are slopes from 30° to 41°, corresponding to Alpine conditions. Similar gradients have also been determined along the front of the

continental slope of California where 35 profiles between San Diego and Point Conception have shown an average inclination of 13.7 between the general isobathic contours of 2,000 and 4,000 meters.

The future doubtless holds in store the disclosure of many significant details in the configuration of the bottom of the ocean. In its present stage, the bathymetry of the ocean has served in the main to portray the generalities of conformation, consisting of rises and basins which seem to be continuous over enormous tracts of the Earth's crust, exhibiting a scale of structure much larger than that in which orography is usually contemplated. The great rises, such as the Mid-Atlantic Rise and the Easter Island Rise, are as large as whole continents; and the basins which flank these elevations are of continental extent.

The deeps are not, as might sometimes be thought, the pits of the basins, marking the limit of the contracting areas inclosed by successive contours of increasing depth; they are, as a rule, far removed from the middle part of the great oceanic basins, and, by contrast, are found near the bordering lands where displacement phenomena have taken place on a large scale. Thus, in the North Atlantic Ocean, the greatest deeps are associated with the Great Antillean arc, in the South Atlantic with the Patagonian arc, in the Indian Ocean with the Java-Sumatra arc, and in the Pacific Ocean the most of them are along the island-studded ridges on the continental borders of the ocean. It is characteristic of them to be attended on the side toward the ocean with a rather low rise ascending by gentle slopes from the neighboring oceanic basin of 6,000 meters and more in depth, and on the other side descending more steeply into the depths of the trough, from whose bottom the ascent toward the continental or the insular shelf proceeds by comparatively steep gradients. These characteristics may be seen in the contoured chart of the Porto Rico Deep, which was exhibited.

During the earlier months of the present year, numerous echo-soundings were measured for the development of profiles of the conformation of the bottom of the ocean in the West Indian region by the U.S. Submarine S-48 accompanied by the U.S. steamer *Chewink*. These vessels were participating, under the authorization of the Secretary of the Navy, in the International Scientific Expedition to the West Indies sponsored by Princeton University, under the leadership of Professor Richard M. Field. The profiles, which connect in succession more than half a hundred stations for the determination of the intensity of gravity at sea in the circuit of Jamaica and Cuba and in the channels and bordering oceanic tracts of the Bahama Archipelago, form a serviceable contribution to the eventual delineation in detail of the contours of configuration of the submarine physiography of these tracts. Along the routes of the Expedition, as depicted upon the charts prepared in the U. S. Hydrographic Office, selected soundings at close intervals have been registered in a distinctive manner.

U. S. Hydrographic Office,
Washington, D. C.

THE APPLICATIONS OF SEISMIC METHODS TO SUBMARINE GEOLOGY

E. DeGolyer

In proposing the so-called seismic or sonic method as a tool for the geologic investigation of ocean-bottoms and margins, I am aware that I am recommending a method not widely known, and one practically untried for the purpose under consideration.

The problem of working from the ocean-surface, instead of from a land-surface, will require the development of a special technique, but it presents no major difficulty; in fact, it has decided advantages. I am confident that the method can be developed into a tool equal or superior to any now at the command of the geophysicist, geologist, or oceanographer for investigating the constitution and structure of that great and almost unknown portion of the Earth--the ocean-bottoms.

The so-called seismic or sonic method as a tool for the investigation of the sub-surface of the Earth's crust consists essentially in the generation at a known time of a train of sound-waves in the Earth by use of explosives; the recording of the time of

arrival of such waves at points known distances away; the calculation of probable travel-paths from known distances, times and geo-velocities or of geo-velocities from known distances, times, and travel-paths; and deductions as to geologic conditions most likely to fit such solutions of the data.

In actual practice, the sound-waves are generated by the explosion of a charge of dynamite at the surface of the ground or, for greater effectiveness, planted in a hole a few feet deep; the exact time of firing is transmitted to the recorder by radio or a wire-circuit; detectors consisting of mechanical or electrical seismographs or geophones a known distance away receive the wave-impulses and transmit them to a moving record upon which the time of firing is recorded and upon which time-lines are being recorded from one-tenth to one-hundredth of a second apart. The most commonly used form of recorder consists of an oscillograph which records the time lines in hundredths of seconds, time of firing, and variations of current generated or impressed by the impulses received from a number of independent detectors.

There are really two distinct methods, namely, the refraction- and the reflection-methods. Each has its own distinct instrumental requirements, technique, calculation, and purpose.

The refraction-method comprises essentially the firing of a charge or charges at a fixed point and the recording of the time elapsed before the arrival of the first waves at detectors spaced at various distances, usually in a straight line away. Either mechanical or electrical seismographs or geophones are used as detectors and from the data so secured time-distance curves are constructed. The travel-path being reasonably well known, the data is solved for velocity of wave-transit. These geo-velocities, in certain geologic provinces, are diagnostic of the type of rock through which the waves have passed. Depths can also be computed, but the method is essentially one for identification by geo-velocities. The greatest success of the refraction-method to the present time has been in prospecting for salt-domes in the Gulf Coastal plain of Texas and Louisiana. In a country rock of clays, shales, and sands having the definite geophysical characteristics of geo-velocities of approximately 6,000 to 7,000 feet per second, occurs isolated conical or tubular masses of rock-salt of circular plane-section and generally one to one-and-one-half miles in diameter, the salt having geo-velocities of 13,000 to 15,000 feet per second. Manifestly, the arrival of the first wave at detectors five to six miles from the shot-point in transit-times corresponding to the normal regional geo-velocity of 6,000 to 7,000 feet per second, indicates an absence of salt to the depth explored, while any arrival in less time, generally referred to as a "lead," indicates the possibility of a buried salt-mass and is occasion at least for a more detailed investigation.

The entire area was surveyed by fans--a series of one-point refraction-profiles with the shot as a common point and with three or four detectors spaced one to one-and-one-half miles apart on the arc of a circle having a radius of five to six miles. Salt-domes were indicated, generally by leads of 0.20 to 1.0 second, and were proved practically by shooting a more detailed profile from which exact geo-velocities could be computed.

It should be noted here that what the geophysicist actually proves, is the existence of rock with a geo-velocity of 13,000 to 15,000 feet. The reasonable geologic explanation for this is the existence of a salt-dome. The geologic solution of similar data for other areas can be, and is, radically different, since any number of different rocks--granites, basalts, slates, limestones, etc.--have geo-velocities as great or greater than rock-salt.

In the reflection-method smaller charges of explosive are used, the shot and detectors are much closer together, electrical seismographs or geophones of higher natural frequency than those generally used for refractions are used, geo-velocities must be known or assumed, the travel-path is known or assumed, wave-impulses in the train following the first arrival must be picked, and the data are solved for depth to reflecting-surfaces.

A special case of the reflection-method is the so-called dip-shooting, where reflections are recorded from a number of geophones on the same record, and the dip is computed from differences in time of reflection from the various geophones. This

method is chiefly usable for rocks dipping at an angle greater than two degrees. As it is strictly a differential method it is not necessary to record the time of firing the shot.

The reflection-method has been used with great success in Oklahoma for determining the structure of the Viola limestone at depths of 4,000 to 12,000 feet below the surface. It has been proved by drilling, and found to be generally accurate to within one-half of one per cent.

The accuracy of this method depends, among other important factors, upon being able to check velocities by shooting near old wells, and by shooting at the surface near deep wells, and recording time of transit from geophones lowered to the bottom of such wells. No limitation as to depth has been found in commercial work except the very practical one of securing useful information. Reflections are believed to have been secured from the granite floor of the San Joaquin valley in California at depths greater than 25,000 feet below the surface.

So much for these two methods which have been developed and proved as a practical matter in the exploration for new oil fields. Some idea of the extent of their development in commercial work may be gained from the estimate that between thirty and forty millions of dollars have been spent within the past ten years on the development and use of these two methods in geophysical expense alone, and of current expenditures for the same purpose at a rate in excess of two million dollars per year.

This work has been confined fairly strictly to a few areas, and has not been carried on over a wide range of conditions from the viewpoint in which we are interested. Almost no work has been done in igneous nor in metamorphic rocks, and very little has been done in the older sedimentary rocks. Technique and methods of interpretation which would be useful in the study of such rocks have been developed. Refraction-profiles long enough to carry exploration to considerable depths, if they showed velocities lower than 15,000 to 16,000 feet per second, would indicate sedimentary rocks. Higher than that, they would be indeterminate but, if extremely high, would probably indicate igneous rocks. Reflection-shooting would give definite structural information.

In making these statements, I have assumed investigation in an area as far from land and as unknown as the Atlantic Ridge or some of the profound deeps. Such investigation would be under the most adverse conditions. A more rational and favorable method of attack would be to work from a marginal or known area out to the unknown. A line of profiles--refraction and reflection--from a known island or marginal area seaward, for example, might be extremely profitable and informative. This is equally true for the land investigations where deep wells, mines, etc., are available as controls for geophysical extensions. From the known to the unknown is a method of procedure which is as promising in geophysics as in other sciences.

As near an approach to work of the type under consideration as has come to the writer's attention is the survey by the refraction-method of some two million acres of swamp and water-areas of southern Louisiana by the Geophysical Research Corporation. The object was a search for salt-domes. The work was done from a fleet of launches. Shots were placed in the water or on land as was most convenient, and detector-positions were chiefly in the water, geophones being placed on bottom often in depths of 30 to 40 feet of water. The survey was quite successful, some 10 to 11 domes being found, practically all of them in water areas. The first two domes found were South Calcasieu and Vermilion Bay domes in Lake Calcasieu and Vermilion Bay respectively, and each of them was approximately three miles from the nearest shore.

In the seismic surveys of the types which have been made to date in water-areas, the geophones have been placed on bottom--the depth of water not being greater than 30 to 40 feet. This method could be used up to considerable depths in ocean-work, but would require considerable cable and, except in very special cases, would present no considerable advantage over the use of geophones suspended from submerged buoys a few feet under the surface. Geophones having a natural frequency higher than that of the water-motion would be used, and the only need for suspension from buoys would be to avoid the possible effect of water-ripples on the lead lines.

Shots could be fired from near the surface of the water with radio or wire-circuit time-signals, or without time-signals by using the velocity of sound in water to check time.

The chief disadvantage of oceanic work lies in the necessity of working from boats. Among the apparent advantages are the excellence of water as a medium in which to shoot for the purpose of getting energy into the Earth, the probable ease or lack of necessity for making velocity-corrections for the some of high variable velocities near the surface--the so-called weathered layer--and the fact that in fairly deep water, through the use of long cables from geophones to oscillograph in conjunction with geophones near the surface and the ability to place charges over a great range of depth, the various points of shooting and observing would have possibilities of a three-dimensional arrangement instead of the two-dimensional arrangement to which one is practically limited in working from the Earth's surface.

It is possible, where reflections are the thing desired, and the work is to be done in water with a depth of a hundred fathoms or more, to design an arrangement whereby the recording can be done from a single boat, the charges being fired near bottom by the use of an especially devised depth-bomb.

In fact, when one considers the possibilities of ocean-shooting it opens up a fascinating field of speculation as to improvement in methods and technique.

Geophysical Research Corporation,
New York, New York

TORSION-BALANCE SURVEYS IN SOUTHWEST LOUISIANA AND SOUTHEAST TEXAS

D. C. Barton

Extensive detailed areal torsion-balance surveys with which I have been connected or studied extend from the south end of the Sabine Uplift to the Gulf and from the vicinity of Houston half way east to New Orleans, and I have had connection with patchy surveys in the Mississippi delta-area and in the coastal area southwest of Houston which give a somewhat impressionistic picture of the regional variation of gravity. From those surveys, a picture of the broad variation of gravity in Louisiana, in east Texas, in southeast Texas, and in south Texas is shaping itself in my mind. But the pattern of the broad variation of gravity is not simple and the data now available show that haste must be made slowly in filling in the many broad gaps in the picture and in drawing conclusions from the gravity-data of those torsion-balance surveys and of the pendulum-surveys.

The following comments summarize my current, very tentative conclusions in regard to the significance of the major features shown by the fragmentary picture now available to me of the variation of gravity in the Gulf Coast area:

(A) The salt-domes of southwest Louisiana and southeast Texas lie in a broad areal gravity-trough, which is especially sharp in Louisiana and whose crest coincides with the Southern Pacific (or southern Louisiana) salt-dome line between Lake Charles and Crowley and runs approximately across the Vinton-Loockport-Iowa-Welsh-Roanoke-Jennings salt-domes.

(B) It is a question whether that trough of minimum and the other anomalies reflect anything more than the conformation of the salt-series. The large anomalies certainly in large part are reflecting the conformation of the salt. But if there were a large broad salt-ridge axially located in the trough of a deep geosyncline, it would be difficult to separate the gravity-minimum which would be produced by the convex salt-mass of negative relative density from the minimum which would be produced by the concavity of the basement, which of course is of positive relative density. [Note: Relative gravity determined from torsion-balance observations is relative gravity in any one of the equipotential surfaces at the general level at which the observations were taken--except for anomalies which are produced by bodies close to the surface--and, therefore, are comparable to pendulum-observations of relative gravity reduced by

the free-air method to a common equipotential surface. The observed values of gravity of the Meiness survey were used but were corrected crudely for the effects of the slope of the sea-floor.]

(C) Four alternative hypotheses will explain that trough of minimum through southwest Louisiana and southeast Texas.

- (1) It may be wholly a salt-effect.
- (2) It may be the effect of a geosyncline in which the salt lies axially and is arched up convexly into a salt-ridge.
- (3) It may be the combination (a) of the seaward dip of the sediments and the basement on which they rest and (b) of the normal increase of gravity which is rather commonly found toward the central portions of ocean basins. The seaward dip of the sediments and the basement should give an increase of gravity inlandward. Meiness has mapped the increase of relative gravity from the Texas-Louisiana coast toward the central portion of the Gulf of Mexico.
- (4) It may be the more complex combination of any or all of the preceding factors; that is, it may be a combination of (a) a salt-effect, (b) the effect of a geosyncline in which the salt is located more or less axially, (c) the effect of the regional coastward dip of the sediments and the basement, and (d) the increase of gravity toward the center of a large ocean basin.

Geologically, it is necessary to assume the formation of a deep geosyncline under the Gulf Coast area. Our sedimentary section is very thick. The base of the salt-domes in the Houston district on the basis of geophysical data must lie at a depth of at least 15,000 feet and more probably 20,000 feet. The drill has shown that at Sulphur, Louisiana, the base of the salt is below 9,200 feet. In the Mississippi delta-area, south of New Orleans, the Tertiary section through the zone reached by the drill is one-and-one-half to two times as thick as in the Houston area. Most of the sediments which are reached by the drill are shallow-water deposits, many of them brackish-water deposits. Sinking of the sediments, therefore, has been concomitant and in general equal to the sedimentation. Flowage of the unconsolidated sediments toward the unsupported edge of the continental shelf may have caused part of the sinking but cannot have produced all of it and much of it must have been caused by depression of the basement.

The axis of greatest thickness of sedimentation does not coincide with the axis of that trough of gravity minimum through southwest Louisiana and southeast Texas. The former lies at or off the coast except possibly at the southern edge of the Mississippi delta where it should lie on the delta, but the axis of the latter, the trough of minimum, lies about 50 miles inland in southwestern Louisiana.

Such a shift of the axis of the minimum would be produced if a normal increase of gravity toward the center of a large ocean-basin were superimposed on the minimum produced by the geosyncline. But more data are necessary to prove quantitatively that such is the case in southwestern Louisiana.

An inconsistency arises in the fact that there is a positive anomaly over the lower Mississippi delta which is the area in which there has been the greatest sedimentation. The anomaly doubtfully could be the effect of an extra load on a mechanically strong competent basement, for geologically there must have been the maximum depression of the basement in that area, although in part, the delta has been built out and above what would be the surface of the continental shelf without that sedimentation. I have not attempted calculation of what the effect of that excess of mass should be.

If a slight westward curvature is given to the Appalachian trough and the Appalachian piedmont belt, the minimum trough of southern Louisiana and southeast Texas is in prolongation of Bowie's area of negative isostatic anomaly which more or less coincides with the Appalachian trough and the south-southeast side of the southern Louisiana to southeast Texas trough of minimum would be on the prolongation of the northwest flank of Bowie's area of positive isostatic anomaly which more or less coincides with the Appalachian piedmont belt.

Those suggestions are the result of my study of data which are available to me, but unfortunately those data are not yet sufficient for the solution of the answer to those speculations.

Petroleum Building,
Houston, Texas

EXPERIENCES OF A SEISMOLOGIST WITH "SEISMIC METHODS"

Arthur L. Day

To be the speaker immediately following Dr. DeGolyer is an unexpected pleasure for he has presented to you a very clear picture of the kind of tools which the oil explorations of recent years have made available for geological studies of various kinds. My purpose, following him, is to give you an account of an attempt which was made to go beyond the oil regions with the same equipment in the hope of getting more information of geological value.

Some three years ago I had the honor to be the guest of the petroleum geologists in New Orleans, and at that time a good deal was said, in the section devoted to methods and accomplishments, about the accuracy which had been attained by several of the methods in the field. I may say that the results there presented were impressive, just as it impressed you today when Dr. DeGolyer said that the records obtained with such field equipment showed complete concordance within something like one-half per cent. The time seems to be ripe for taking these methods out of the Texas coastal plain, where they operate in a terrane of uniform geologic structure and giving them a trial under more difficult conditions. The question is, therefore, whether such high precision can be expected and made to do service in fields more complicated and much less well explored. Of course, it was admitted in New Orleans that in a region of greatly distorted structure the problem would be much less simple.

A year ago or a little less the opportunity came to take into the field in California one of the oil outfits as regularly used and just described by DeGolyer, to see what might be done with it on certain specified geological problems. The opportunity came to us through the generosity of Dr. J. C. Karcher and his Company, Geophysical Service, Inc., of Dallas, Texas. The superintendent of the outfit was allowed to go with the apparatus, the plan being to provide us not only the identical apparatus which had been used in oil explorations, but also the person who had been accustomed to interpret them in terms of the experience which had been gained through a number of years of this kind of exploration. With that group of men and equipment went Prof. John P. Buwalda, geologist of the California Institute of Technology, and member of the Advisory Committee in Seismology of the Carnegie Institution of Washington, and Dr. Beno Gutenberg of California Institute, one of the most distinguished of present-day seismologists, and it is the reaction of these men to the method and its possibilities which it is my privilege to report to you very briefly and informally.

May I say that the manuscript of this study which occupied the months of July and August of last year (1931) is complete and in the hands of the Editor of the Bulletin of the Seismological Society of America for printing and in one of the next issues will be available to all. I am sure that in the theoretical treatment which Dr. Gutenberg has there given, supplemented by a discussion of the instrumental technique by H. O. Wood of the Seismological Laboratory at Pasadena and an introduction to the geological problems selected by Prof. Buwalda, will have considerable interest for many of those here present. I have a copy of the manuscript here, but it is 76 pages long and it is out of the question to present it to you in detail. The theoretical discussion alone could not be presented in any such brief time as has been allotted to me. I shall read to you the introduction and certain of the conclusions in order that you may have, in the language of the authors, the results which were obtained in this pioneer exploration which is of exactly the same sort as Dr. DeGolyer has just proposed to you (the exploration of the sea-bottom).

I wish also to emphasize this detail. If you explode a charge of dynamite in the ground and pick up the elastic wave from it with a seismograph you do not in general have the same kind of an elastic wave which is sent out by an earthquake. The reason

is that there is no shear-component from an ordinary blast. If a blast is set off far enough in the ground so that it does not blow out and the maximum amount of energy is delivered to the ground, then you have a compression phenomenon with little or no shear. The result is that the instruments will deal with longitudinal waves only and not with transverse waves. In all of the observations here recorded no transverse wave was certainly identified. Both the refraction- and reflection-methods were used.

The problems upon which we set out were: (a) Velocity of earthquake-waves in different types of rock; (b) depths of two successive rock boundaries; (c) determination of the form of the upper surface in a formational region; (d) determination of the thickness of the granite or continental layer; (e) the possibility of the elimination of the surface-waves by deep surface discontinuities; (f) the presence or absence of a fault and its accurate location; and (g) the dip of a surface-fault. The results will be indicated briefly in the authors' abstract following.

Abstract by B. Gutenberg, Harry O. Wood, and John P. Buwalda

The refraction- and reflection-methods familiar to seismologists have been used by geophysical prospecting companies and petroleum corporations for some years in their search for economic deposits and oil structures. Relatively little has been published, however, regarding the nature and effectiveness of this mode of investigation. As a result of plans formulated by Dr. Arthur L. Day an opportunity was afforded to test the methods and their applicability to several types of structural problems. The experiments were made possible by a grant from the Carnegie Institution of Washington and through the generous cooperation of Dr. J. C. Keroher and Mr. Henry Salvatori of Geophysical Service, Inc., of Dallas, Texas. The field studies occupied most of July and August, 1931.

Experiments were carried on in four localities. In the Los Angeles Basin stations were occupied along a line extending from a point about one mile north of Wilmington to a point about four miles northeast of Artesia. The maximum thickness of post-Jurassic sediments is probably between 7 and 14 kilometers. By reflection a number of layers were indicated in the records, down to a maximum depth of 3-1/2 kilometers, and in a few records to a somewhat greater depth. It is probable that better results could have been attained in wet soil during the rainy season and with a higher water-table. In the refraction experiments the maximum distance utilized between explosion and recording points was eight kilometers and the deepest layer detected was at about two kilometers. Interference from highways and buildings prevented use of a longer line of explosion points. Velocities ranged from about one km/sec. in alluvium to over 3.5 km/sec. in consolidated Tertiary sandstone at depths of about 1,700 meters.

In the Ventura Basin, near Oxnard, the attempt was made to trace the surface of a basaltic formation dipping from the north base of the Santa Monica Mountains northward beneath the valley floor. Excellent reflections were secured from the basalt to a depth of 2.3 km beyond which observations were not carried.

At Yosemite Valley the experiments were facilitated by the construction of a road tunnel through the cliffs on the south side in which charges of dynamite up to 500 pounds were detonated. Records were secured at Gentrys, which is approximately 2 km to the north and across the Valley, also at a point one mile east of the tunnel, and at a point immediately above the explosion. Reflections from the base of the granitic layer, indicating its thickness, had been considered a possibility, but no definite reflected waves were recognizable in the records. Surface-waves were greatly weakened at Gentrys, due to interposition of the valley.

The velocity of the longitudinal waves in granodiorite was measured at Cascade Creek, north of Yosemite Valley, and found to be 5.25 ± 0.1 km/sec.

At Shepherd Creek, in Owens Valley, records were made with explosion and recording points on the alluvial fan sloping eastward from the main Sierran fault. No reflections were secured from the fault-surface nor from the granite floor of the fan. The fault is shown clearly in the refraction-seismograms made with explosion and recording points on a line parallel and close to the fault. On a line at greater distance a deeper layer in the fan, possessing the velocity of alluvium, is shown by refraction but the fault is not evident in the record, suggesting that it dips too

steeply to yield strong waves with the vertical component necessary for registration.

Along the west side of the fault bounding the east base of the Alabama Hills, about five miles south of Lone Pine in Owens Valley, measurement of velocity in the Triassic metamorphosed shales and pyroclastics yielded 3.1 km/sec, or considerably less than in the granodiorite at Yosemite Valley.

East of the fault the thickness of the soft Quaternary clays was found by reflection to be about 110 meters along one line of explosion points parallel to and 46 meters from the fault and the same within limits of error along another line at a distance of 210 meters from the fault.

Along the first line the 110-meter thickness was corroborated by the refraction method and the velocity in the crystalline rocks beneath the sediments, presumably of the same nature as those west of the fault, was found likewise to be 3.1 km/sec. Because no reflections were recorded from the fault in any of the records it is inferred that the fault is steep.

Although it may be difficult at times to secure by reflection and refraction all the results claimed by the most ardent enthusiasts, the authors are convinced that these methods constitute a powerful new tool for determining crustal structures. By reflection, depths and thicknesses can be determined down to 10,000 feet and, under the most favorable conditions, to perhaps double that depth. Particular boundaries between formations can be traced at these depths and the structure thereby determined. The refraction method likewise permits determination of depths, thicknesses, the tracing of formation boundaries with resultant recognition of structure, and in addition the respective velocities. Data regarding the existence and dip of faults can be secured by both methods.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

DISCUSSION FOLLOWING SYMPOSIUM

T. Wayland Vaughan (Scripps Institution of Oceanography, La Jolla, California)--This discussion has greatly interested me. As I listened I had a feeling of sadness. Except for Mr. Robert T. Hill, I believe that the beginning of my own field work in the West Indies antedates that of any other living man. This month, 31 years ago, I was engaged in field work in Cuba. It is pleasing to the old workers that some of their important findings, which were the results of rough reconnaissance, have been corroborated. One of those findings was the tilting of the terraces along the south side of Cuba--the terraces rise in altitude toward the east. I think that in the report on Cuba we first published that the southern coast of Cuba is a fault-coast. I am not sure whether it was Father Scherer or I who first advanced the explanation that the Bartlett Trough is due to block-faulting. I may have been the first, but Father Scherer was working on the earthquake-lines of that region and many years ago recognized the relation of the Bartlett Trough to earthquake-zones.

Later, I was the supervisor of the geological surveys of the Dominican and Haitian republics. The eastward extension of the Bartlett Trough into the Cul de Sac plain of Haiti was noted. Although the Cul de Sac valley is due to faulting, Woodring showed that there were compressed, overturned folds, as well as faults. The possibility of faulted folds, as well as block-faults, should be borne in mind.

In connection with the studies in Cuba, Haiti, and the Dominican Republic, I tried to get a series of lines of soundings run across the Bartlett Trough to develop the submarine topography. That was not done then, but it has been done since. I also tried to get more gravity-stations established on the sides of the Trough, and to get a net of seismological stations established in the island of Haiti, some in the Dominican Republic, and some in the Haitian Republic. In those endeavors I did not succeed. At the time of the investigations mentioned the Vening Meinesz apparatus was not available. Therefore, it is now possible to do one thing which could not be done then. It is gratifying to everybody who has been active or interested in the geology of the West Indies that the work on gravity has now been done. I wish to suggest that the determinations of gravity be extended so as to take in the Anegada Trough, the main Virgin Island Ridge eastward from Porto Rico, and the Island of St. Croix, and that the islands of St. Martin and Anguilla be included in the program. The Anegada Trough is similar to the Bartlett Trough, although not quite so deep. We need to have the gravity-determinations made not only at sea but also on the adjacent land-areas.

From this discussion I have received from Dr. DeGolyer and Dr. Day two valuable suggestions that bear on problems with which I am now concerned. For a long time we have wished to measure the thickness of the different kinds of deep-sea sediments. Apparently the petroleum geologists have given us a method. We have also wished to measure the thickness of the limestone in coral-reef areas. Under the International Committee on the Oceanography of the Pacific there is a sub-committee on the application of geophysical methods to the study of coral reefs, which will report in Vancouver a year from now. The papers by Messrs. DeGolyer and Day give us hope that we may be able, by the use of seismic methods, to get the desired information.

Mr. Chairman, I congratulate you and those who have taken part in this symposium; it has been one of the most interesting that I have attended.

Richard M. Field (Princeton University, Princeton, New Jersey)--Perhaps a number of the members present were not acquainted with the work which Dr. Vaughan has already done in the region of the Bahamas. In my own case, I entered the region largely due to the stimulus afforded by Dr. Alfred G. Mayor in 1916 while I was working at the Tortugas laboratories. Had it not been for Mayor, Vaughan, Drew, and Goldman, the present comprehensive plan for the investigation of the West Indies region would probably not have originated. We are particularly indebted to Dr. Vaughan for the problems which he has raised in connection with the carbonate-deposits in the Bahamas.

N. H. Heck (U. S. Coast and Geodetic Survey, Washington, D. C.)--I would like to ask Dr. DeGolyer a question. He spoke of firing explosives at a moderate depth below the surface. If that is correct, how much of the energy is likely to go into the bottom?

E. DeGolyer (120 Broadway, New York, New York)--I cannot answer the question because we lack data. We plant our shots in the ground in order to get more energy into the ground. In water-areas we should expect much better results than in land-areas.

A great reduction in the amount of explosive required to be used in order to get satisfactory reflections has been one of the outstanding improvements in recent reflection-technique. Dr. Karcher recently told me that the average amount of dynamite used for seven or eight crews working for depths of 4,000 to 5,000 feet over a period of three months was some seven ounces per shot. I have seen beautiful reflection-records from similar depths secured from a dynamite-cap. For refraction-shooting, much larger amounts of dynamite are necessary.

William Bowie (U. S. Coast and Geodetic Survey, Washington, D. C.)--Dr. DeGolyer pointed out the fact that the difficulty of working at sea was getting ships. The vessels of the Coast and Geodetic Survey have for the last two years been making a survey of the Georges Bank. Would it not be possible to carry on some of this seismic work in connection with their regular echo-sounding and radio-acoustic ranging work? The distances apart of the vessels are known with extreme accuracy, a few feet per mile, and I think it would be a good idea if some organization would co-operate with those vessels and perhaps make the first test of the seismic method at sea on the Georges Bank.

T. Wayland Vaughan--Is it possible to operate, from small boats such as those usually carried by large vessels, the explosives and the other necessary apparatus for applying the seismic method to the determination of the thickness of deep-sea bottom-deposits?

E. DeGolyer--Yes, this could be done quite readily if you had either some land-station or mother-ship to work from. The recording-apparatus is now carried in a car and it is not so heavy or unwieldy but what it could be transferred to an ordinary small boat.

Francis P. Shepard (University of Illinois, Urbana, Illinois)--With regard to the submarine valley which was mapped during the recent expedition, I note that Dr. Hess's contours depict some features similar to those shown by the submarine valleys which I have described as the river-valley type. The outer depth of 2,200 fathoms is not in excess of that shown by the great valley off the Portuguese Coast, just north of Lisbon. Also the patterns of the valley with its right-angled bends suggesting control by hard and soft tilted layers is duplicated by the same valley off the Portuguese Coast. The same is true of the rough V-shape of the outer part of the valley. On the other hand, the inner portion of this feature with its broad base and steep sides is quite different from the river-valley type of submarine valley and suggests that it was formed by block-faulting. I wonder if the feature is not a combination of a submerged river-cut valley and a fault-trough.

Carroll H. Wegemann (102 West 39th Street, Baltimore, Maryland)--I am very much interested in the map which Dr. Hess threw on the screen showing the details of the Bartlett Trough. It seems to me that this map shows two principal structural directions, one about north 30° west and the other north 70° east. These two directions are the dominant directions throughout the Rocky Mountain region. The former is that of the mountains of Mexico, and is the direction of most of the principal folds of the Rockies. North 70° east is the direction of many faults in Cuba as well as on the continent.

Harry Fielding Reid (Johns Hopkins University, Baltimore, Maryland)--The linear arrangement of mountain ranges is explained by the work of James Hall, who, in 1859, taught us the history of the Appalachians. He showed that the great mass of deposits, later to become a mountain range, was deposited near a coast-line, and therefore the range was naturally linear. There is abundant evidence in the folding of the strata, the slaty cleavage, the distortion of the fossils, that the whole was subjected to great horizontal compression. But the mountains of the present day do not owe their elevation to this compression. For geologic history teaches that after the compression some ranges sank below the sea, were covered with later strata, and later still were raised without further compression; others were peneplained and then raised without distortion of the peneplain. These considerations make it evident that the

elevation was due to vertical forces, and that they acted in some cases whole geological periods after the compression. The existence of steep faults bordering some ranges confirms this idea, for such faults can only be formed by vertical forces.

The linearity of ocean-deeps is not so easily explained. They all lie near and parallel to high land, and they form part of a curious profile. To the geologists of the last century this naturally suggested a simple fold due to compression; but modern gravitational observations do not support this idea; for though the anomalies are negative over the deeps they are not nearly as strong as they would be if the profile were due to squeezing out material from the deep and forcing it under the dry land. The close connection between deeps and mountain ranges certainly suggests some relation between them, but what it is is obscure.



In studying great earth-movements we have two factors to consider: (1) The character of the forces and (2) the character of the Earth's crust. We may assume the forces which fold the strata as general, such as would develop in a shrinking globe, and explain the local folding as due to a "zone of weakness"; or we may assume local forces acting over limited regions. It is only by detailed studies that definite information on this subject can be obtained.

It has been suggested that earthquake-centers sometimes lie along a closed curve, as shown, for instance, by the origins around the Caribbean Sea. Earthquakes occur where the differential earth-movements set up stresses strong enough to develop faults, and would naturally surround an area which was moving as a unit. But other cases occur. The Sierras are moving like a tilted block; earthquakes are frequent along the great boundary-fault on the east, but along the western limit of the range they are rare.

William Bowie--Mr. Littlehales spoke of the deviation of the water-surface from the mathematical surface. The best evidence we have indicates that the deviations are seldom more than 100 meters (approximately 300 feet). Such small differences would not affect our thoughts in trying to correlate the depths of the oceans with the elevations on the land. It has been stated by some geologists and geodesists that the differences between the geoid and spheroid are as great as 1,000 or 2,000 feet, but it seems to be certain that they are not nearly so great.

G. W. Littlehales (U. S. Hydrographic Office, Washington, D. C.)--Dr. Bowie's estimate of the order of magnitude reached by departures of the surface of the geoid from the surface of the theoretical ellipsoid on the ocean somewhat exceeds the order of magnitude of the elements commonly recognized as necessary to be introduced, in order that the depth determined may be the result of applying to the measured interval of time the proper velocity of sound due to the state of density and compression of the water-column in which the sounding was taken. Being, however, of a nature distinct from the measurement of depths, the departures referred to are of present concern only in relation to transferring to the theoretical spheroid the system of mapping the features of the bottom of the ocean which now proceeds by reference to the surface of the geoid.

Arthur Keith (U. S. Geological Survey, Washington, D. C.)--Dr. Taber spoke to me yesterday about some granites which he saw on the island of Cuba and I would like to have Dr. Taber speak if he will.

Stephen Taber (University of South Carolina, Columbia, South Carolina)--The granite, to which Dr. Keith refers, I would call granodiorite. It is part of a large batholithic intrusion that is exposed along the coast of Cuba for a distance of over 100 miles. Portions of it had been mapped previously in the vicinity of the iron mines east of Santiago, now operated by the Bethlehem Steel Corporation. This rock forms some of the highest peaks of the Sierra Maestra, such as Turquino, which is nearly 7,000 feet high.

Along the contact with the stratified rocks there has been considerable metamorphism. Limestones have been converted into marble and large masses of garnet have been formed. The granodiorite grades into basic differentiates near the contact, and

the iron ores, which are associated with these basic rocks, have been formed, in part at least, by replacement of limestone. The stratified rocks are much tilted and disturbed in the vicinity of the batholith, and also near some of the larger dikes, so that in places the dips are vertical.

The copper deposits at Cobre are probably genetically related to the intrusions, as they are located in the stratified rocks not very far from their contact with the granodiorite.

There is some evidence that granodiorite may have once formed the top of high mountains along the coast near Daiquirí and probably south of the present coast-line in the area now occupied by the Bartlett Trough, for I found a thick bed of conglomerate containing many granodiorite pebbles on the north side of the present mountain range at a point opposite to Daiquirí.

Dr. Vaughan asks me to say something about the age of the rocks. The oldest rocks encountered are the metamorphic rocks found east of Guantánamo Bay. Their age is unknown. The oldest fossils found in the area were obtained several years ago by Miller and Singewald from a limestone associated with the iron ore-deposits near Daiquirí. Dr. Vaughan identified these fossils as Cretaceous in age. The Cretaceous limestones are interbedded with quartzites and more or less metamorphosed shales--rocks which are quite different from the overlying series.

At one place near Vinent, I found above the iron ore-formation a conglomerate that graded upward into volcanic breccia. The explosion-breccias and volcanic tuffs, with some interbedded limestones and lava-flows, form a very thick series that seems to be Eocene and Oligocene in age, but all of my fossils have not as yet been identified, so the ages assigned are tentative. This series of rocks covers a large area in the Sierra Maestra. The granodiorite is probably Oligocene in age.

In the vicinity of Santiago, marl-beds, identified by Vaughan as middle Miocene, rest on the eroded surface of the older rocks, and similar marls were found near Mansanillo and Media Luna north of the western end of the mountain range.

Dr. Hess presented a theory, advocated by Meissner, that there may have been shearing in the region somewhat similar to the shearing in California, and that this had resulted in tension accompanied by gravity-faulting. No evidence was found by me that would support this theory. The fresh excavations along the new highway that goes west from Santiago, and also the excavations along the Santiago aqueduct, were carefully examined for evidence bearing on the nature of the faulting. The aqueduct runs along the base of the Puerto Pelado fault-scarp until it dies out and then follows along the base of the Sierra de Boniato scarp to a point near its western end, where a tunnel passes directly through the range. At several places in these excavations beautiful slickensides and fault-striae were exposed, and in every case the striae indicate vertical or nearly vertical displacements.

If the faulting along the rim of the Bartlett Trough is due to gravity, we would expect to find step-faults, but none was found. The youngest faults are those farthest from the center of the trough and the displacements have resulted from the uplift and northward tilting of crustal blocks. The displacements here are not due to downthrow but to upthrow. This is clearly shown by the rejuvenation of the streams that flow down the back slope of the fault-blocks and by other evidence.

The Bartlett Trough has been formed by down-faulting, probably under the influence of gravity, but the land along the rim, at least in Cuba, has at the same time been uplifted.

Richard M. Field--In closing the discussion, I would like to state that I have here a letter from Dr. Barton, in which he sums up the paper which he could not be present to present at the symposium. As this paper materially helps to round out the program, it will be published together with the rest of the papers.

As the symposium was intended primarily to emphasize the application of geophysical technique to the structural study of ocean-basins and their margins, I have

been very much pleased that, with few exceptions, hypotheses and theories have not tended to overshadow the papers on the succeeding discussions. What we are after is to discover the ways and means of getting more data in the relatively unexplored ocean-basins. I am sure that the geophysicists will forgive the geologists if at times they appear controversial rather than constructive. Perhaps the geologists have helped to bring out still more clearly the nature of the problems which require the aid of the geophysicist. I believe there is no more promising field for the further development of Earth science than the geophysical attack on ocean-basins; and in this connection I would like to say that it is only by a strong cooperative effort that this attack can be effectively and economically carried out. Without the Coast and Geodetic Survey, without the Navy, in all its branches, without the Bureau of Standards, it would have been almost impossible to have carried out the recent expedition in the West Indies. I think I can express, therefore, in the names of all of you, our sincere thanks to those great scientific departments of our Government.

In relation to the International Expedition to the West Indies: It is being planned, through the Hydrographic Office of the United States Navy, to issue a chart which will show not only the gravity-stations determined on the islands and at sea during the last expedition, but also the marine stations determined by Dr. Meinesz with the S-21 and with the Dutch submarine. This chart will also show the gravity-stations on the important contiguous land-areas, as well as the locations of the seismic epicenters both on land and at sea. I shall appreciate it greatly if those desiring copies of these charts, or those already published on the sonic soundings, will be so kind as to let me know.

**BLANK
PAGE**

AMERICAN GEOPHYSICAL UNION
Thirteenth Annual Meeting

REPORTS AND PAPERS

SECTION OF GEODESY

Washington, D. C.
April 28, 1932

CONTENTS

	PAGE
SECTION OF GEODESY.	51
Progress-report on the absolute determination of gravity at Washington. Paul E. Heyl	53
Improvements in the gravity-apparatus of the United States Coast and Geodetic Survey. E. J. Brown.	54
Gravity-observations in the Bahamas. J. P. Lushene.	57
Isostasy and related subjects. F. A. Vening Meinesz	59
Progress-report on radio dissemination of the national primary standard of frequency. J. E. Dellinger	63
Geodetic control for the plotting of the aerial photographs of the Belcher Is- lands. Noel J. Ogilvie	64
Analytical methods in aerial photogrammetry. Earl Church.	68
New comparisons of the invar wires of Mexico. Manuel Medina	76
Progress-report on investigation of invar tapes and precision circles. L. V. Judson.	79
Geodetic work accomplished from May 1, 1931 to April 30, 1932. William Bowie. Further studies on the lunar correlations with small changes in the variation of latitude. Harlan T. Stetson	80
	85

PROGRESS-REPORT ON THE ABSOLUTE DETERMINATION OF GRAVITY AT WASHINGTON

Paul R. Heyl

(Publication approved by the Director of the Bureau of Standards of the United States Department of Commerce)

During the past year the work on the absolute determination of gravity at Washington has made considerable progress, and established several new and interesting facts.

The first of these deals with the suitability of different materials for knife-edges. It is traditional to use agate for this purpose whenever high precision is needed. Steel has always been regarded as a second-grade material.

The use of agate dates back to a time when fused silica was not known. It seemed to us that fused silica might be equally as good and perhaps better. Some months of experience with a knife-edge of fused silica (in connection with a silica plane) has led us to the conclusion that, at least for pendulums of the weight used by us, silica is much inferior to agate. There seems to be a progressive deterioration with use in a silica knife-edge which showed no signs of coming to an end in nine months. Moreover, this deterioration could not be certainly detected by microscopic examination. That it is a reality appears to be established by a progressive alteration of time of swing. In one case we were fortunate enough to observe an actual breakdown as evidenced by a sudden change in the damping-factor during a swing of several hours duration.

Agate has proved itself a much better material than silica, and amply justifies the traditional esteem in which it has been held. It is probable that its superior toughness arises from the crypto-crystalline nature of agate as contrasted with the amorphous character of fused silica.

A second point of importance which has been discovered (or rather, rediscovered) relates to the correction to the time of swing arising from lack of sharpness of the knife-edge. The formula for the reduced time of swing of a reversible pendulum carrying two planes and supported by a single knife-edge is of such a nature that certain corrections will eliminate themselves. The condition for this is that the corrections must be inversely proportional to the distance from the points of support to the centers of gravity of the pendulum.

Now the correction for a circularly rounded knife-edge, or even one of elliptic form, is of this character, and consequently while the knife-edge correction to either of the observed times of swing may be relatively large, in the reduced time of swing these corrections do not appear.

It seems that Bessel recognized this fact, but, probably because the practice of that time was to use a pendulum with two knife-edges, it was not regarded as a matter of practical importance. Reference is made to it by Helmholtz in his "Beiträge zur Theorie des Reversionspendels," but no use was made of it in the Potsdam determination of gravity which was instituted by him and carried out under his supervision, and the point appears to have been completely forgotten.

We have obtained as a provisional value of g in the constant-temperature room in the second sub-basement of the East Building of the Bureau of Standards the value

$$g = 980.073$$

This value is corrected for four of the six corrections to the time of swing. Of the other two, one is the knife-edge correction which is self-eliminating, and the other is the flexure-correction.

The value obtained some years ago by the Coast Survey in the basement of the South Building is

$$g = 980.095$$

greater by 22 units of the third decimal place. The flexure-correction will reduce this difference, and possibly by a major fraction of its amount.

An additional uncertainty yet remains in the length measurement, which, however, will hardly exceed three or four units of the third decimal place. This uncertainty will be resolved when stellite planes are substituted in the pendulum for those of silica.

U. S. Bureau of Standards,
Washington, D. C.

IMPROVEMENTS IN THE GRAVITY-APPARATUS OF THE COAST AND GEODETIC SURVEY

E. J. Brown

The results derived from gravity-observations have three principal applications to geodesy and geophysics: The determination of the figure of the Earth; the investigation of the nature and extent of large geologic formations; the investigation of purely local structure. The Coast and Geodetic Survey is chiefly concerned with the first two of the applications mentioned, and the instruments and methods used are designed to meet the requirements of these two phases of gravity-investigation.

Mention is made of the type of investigation pursued because of the significance it has in determining the accuracy required from the measurements. An accuracy of determination of one part in 200,000 will yield results of value to the geophysicist, and an accuracy of one part in 1,000,000 is ample for any work dealing with the larger structures which form the Earth's crust.

The instruments used by the Coast and Geodetic Survey are designed to give, with normal procedure, results approaching an accuracy of one part in 1,000,000. Where results of greater precision are desired, for use in determining physical constants or other such purpose, the accuracy may be increased by repeating observations. No attempt is made, however, on the general geophysical investigations to meet the exacting demands of geophysical prospecting, where an accuracy of a few parts in 10,000,000 is desired.

The gravity-surveys carried on in the future will probably be of a much more detailed nature than those performed in the past, and they will, no doubt, produce much data of value relative to local structures, through the detection of distinctive regional anomalies. Such information may serve the commercial geophysicist as a reconnaissance survey and perhaps indicate areas worthy of more detailed investigation. It is certain that the knowledge of the absolute value of gravity at many stations comparatively close together will prove of great value on any subsequent surveys by more refined methods.

In determining the intensity of gravity the Coast and Geodetic Survey employs the method of relative measurement by means of a free-swinging pendulum. The apparatus used on practically all of the determinations which have been made to date is known as the Mendenhall invariable half-second pendulum apparatus. This apparatus was constructed in 1890, and except for minor changes is in use at the present time in practically the same form as when first designed.

The essential parts of the Mendenhall apparatus are: Four pendulums, an airtight receiver in which the three working pendulums are swung, a telescope and flash-apparatus for making coincidence observations, three chronometers, a chronograph, an interferometer, thermometers, manometers, and other minor parts.

The pendulums are of invar metal, and are one-quarter meter in length. They are made with a thin stem with a heavy lenticular-shaped bob at one end, and an inverted stirrup at the other end to hold theagate-plane on which the pendulum swings. Three working pendulums and one dummy pendulum comprise a set. The dummy pendulum is similar to the others in material and dimensions, but it is used only as a mounting for the thermometer. It is suspended in a fixed position near the working pendulum in order that the thermometer will indicate a temperature agreeing closely with the temperature of the working pendulum.

The pendulums are swung on an agate knife-edge mounted in a heavy cast-brass receiver which is evacuated to a pressure of about 60 mm of mercury. The receiver is supported by three heavy foot-screws resting on foot-plates. The foot-plates must be mounted on some solid foundation such as solid rock, a concrete floor, or a masonry pier.

The observations consist in comparing the pendulums with two break-circuit chronometers by means of the light-coincidence method. The chronometers are in turn compared with radio time-signals by chronographic registration, their rates determined, and a value of the pendulum period computed. Aro, pressure, and temperature corrections are applied, as well as a correction for the flexure of the support as determined by the interferometer. A complete set of observations ordinarily consists of three swings, of not less than eight hours duration each, and requiring the use of two different pendulums.

The results obtained with the Mendenhall apparatus have been of a uniformly high order of accuracy and meet the requirements of present-day practice in that respect. The nature of the apparatus and the observing methods employed were such, however, as to require a rather long period of observation for each field station determined. It was believed that certain improvements could be made, whereby the speed of operation could be increased considerably without impairing the accuracy of the results.

The new apparatus to be described, in which these improvements have been incorporated, employs the same type working pendulum and knife-edge as is used in the Mendenhall apparatus. It is probable that the pendulum design could be improved upon but the time and facilities available were too limited to permit the investigation of new pendulum types. The principal points of difference, as compared with the Mendenhall apparatus, may be briefly stated as follows: New receiver design which provides means of carrying the working pendulum in the receiver during transportation of equipment; a change in the method of supporting the receiver whereby the effects of flexure are reduced and the necessity for a specially prepared foundation is eliminated; recording instruments of such design as to permit the pendulum to be directly compared with the radio time-signals; elimination of the dummy pendulum; the permanent mounting of all recording instruments in a suitably constructed automobile truck body.

In using the Mendenhall apparatus it was necessary to open the receiver and remove the working pendulum before the equipment could be transported. With the new apparatus one working pendulum may be left in the evacuated receiver for as long a period as is desired. The necessary manipulation of the pendulum, such as clamping or unclamping, lifting from the knife-edge, or starting and stopping, is all accomplished by one external control.

The dummy pendulum is not used, as it was found that more accurate temperature-readings were obtained by mounting the thermometer in a smaller mass of invar. The thermometer and manometer are held vertically inside the receiver and are read through the receiver cover, which is of plate glass, by means of a reflecting mirror and a reading telescope.

Measurements of flexure made on the Mendenhall apparatus clearly indicated that a considerable portion of the movement occurred in the region of the foot-screw assemblies. It was believed that part of this movement was due to compression of the points of the foot-screws, and part of it caused by lack of rigid attachment of the foot-screws to their support. In an attempt to reduce the effect of the flexure resulting from the causes mentioned, two unique features were incorporated in the design of the new receiver. (1) The three points of support were not placed at the bottom of the receiver as in the Mendenhall apparatus, but were so raised as to define a plane at the approximate elevation of the knife-edge. This feature of design tends to decrease the horizontal component, at the knife-edge, of any movement occurring at the points of support, and thus reduces the effect that such movement has on the period of the pendulum. (2) The foot-screw assemblies were so designed as to give large bearing surfaces to carry the weight of the receiver, and to permit the receiver to be rigidly clamped to its support.

The support for the receiver, known as the base-chamber, is in the form of a cylinder with the bottom end closed, and having three leveling- or foot-screws attached

to its top edge. The leveling-screws pass through holes in the support-arms of the main assembly-casting of the receiver, and carry lock-nuts and washers bearing on both the top and bottom surfaces of the three support-arms. The bearing surfaces between the washers and lock-nuts are so turned as to form segments of a sphere when the nuts and washers are tightened against the surfaces of the support-arms. This permits leveling and tightening without inducing undue stresses in the assembly-casting. When solid rock or other stable-surface footing is not readily available for supporting the base-chamber, it may be placed on a bed of plaster of paris in a shallow hole in firm earth. In this way the necessity for specially prepared foundations is avoided and much time is saved in preparing the station.

Flexure measurements were made with both the Mendenhall apparatus and the new apparatus, using the same pier as a foundation. The value of the flexure-correction for the new instrument was less than half that determined for the Mendenhall apparatus, indicating that the changes made in the method of support were effective in reducing the magnitude of the flexure-corrections.

In determining the period of the pendulum with the new apparatus, the pendulum beats are recorded chronographically against radio time-signals. The pendulum registration is obtained by means of a photoelectric cell on which the image of the filament of a galvanometer lamp is impressed, after reflection from a small mirror mounted on the swinging pendulum. A fine bronze wire, made parallel to the filament image, is stretched across the photoelectric cell in such a position as to interrupt the light momentarily during each oscillation of the pendulum. The photoelectric amplifying system is comprised of a Westinghouse type A photoelectric cell amplifier unit, a 240-type tube, and an FG65 thyatron. The output from the thyatron operates the chronograph pen directly. The light-source with its accompanying optical system, and the Westinghouse unit are housed in an aluminum box which is attached directly to the receiver. By having the optical-system housing mounted on the receiver, the process of adjustment, incident to a new set-up, is accomplished very quickly and easily.

A short-wave receiver is used for the reception of the radio time-signals. The output of the receiver is also coupled to an FG65 thyatron and this thyatron operates the second pen of the chronograph. The two thyatrons and the 240-type tube are combined in a single amplifier unit.

The chronograph used is of the drum-type, driven by a spring motor. The drum is driven at the rate of six revolutions per minute, and is of such diameter as to give a recording speed of five cm per second. The chronograph is fitted with a sealing device which permits the records to be read without removal from the drum.

A complete chronographic record of a swing consists of (1) comparisons of the pendulum with time-signals at the beginning and end of the swing, (2) comparison of a break-circuit chronometer with the same signals, and (3) intermediate comparisons of the pendulum with the chronometer. The time-record obtained from the chronometer is not used in making the final determination of period, but only as an aid in counting the pendulum beats.

Convenient means are provided for reading the arc, temperature, and pressure. The flexure is measured with an interferometer of special design. The pendulum may be tested for magnetism and demagnetized if necessary without removing it from the receiver. In general, all accessory equipment has been designed to permit quick handling and rapid observation.

All recording instruments are permanently mounted in truck body of suitable construction. A switchboard, controlling all electrical circuits, is provided to facilitate the operation of instruments and to protect them during transit. The filament supply for the vacuum-tubes is taken from a storage-battery which is charged from the truck generator.

The field observing-program with the new equipment will differ somewhat from that pursued with the Mendenhall apparatus. The customary procedure will probably require a determination with all three pendulums of the set at the first station in any area to be investigated. From then on a single pendulum will be used throughout the area, provided repeat-stations can be occupied at intervals to check possible changes in the

standardized value of the pendulum period. In case the work is of such nature as to prevent reoccupation of stations, it will be necessary to check the constancy of the pendulum by swinging all three pendulums at an occasional station.

The probable-error of observation and the speed of operation which can be obtained from the new equipment are not fully determined as yet. The apparatus is in the field at present on a program of observation comprising some 14 stations, all within about 250 miles of Washington. Results to date indicate that the accuracy desired can be obtained from a single 10-hour swing at each field station, and it is believed that the rate of progress eventually obtained will be two or three times as great as that possible with the Mendenhall apparatus.

Satisfactory progress in the development of this new equipment has been possible only through the splendid cooperation of the Naval Observatory and the Naval Communications Service. The high order of precision of the time-signals has made possible the shortening of the observing-periods very materially, and the recent addition of several signals to the transmission schedule has resulted in a marked increase in the possible speed of operation in the field.

U. S. Coast and Geodetic Survey,
Washington, D. C.

GRAVITY-OBSERVATIONS IN THE BAHAMAS

J. P. Lushens

During the past 30 years many scientific expeditions to the West Indies have been undertaken. One of the most important was made in 1903 by the Geographical Society of Baltimore and known as the Shattuck Expedition. During those expeditions all phases of science were studied except geophysics. It was not until 1928 that the important subject of gravity was considered and observations were made to study the formation and structure of the West Indies. Dr. F. A. Vening Meines of the Dutch Geodetic Commission, at the invitation of the Carnegie Institution of Washington, came to the United States in 1928 and made gravity-at-sea observations on the submarine S-21 of the U. S. Navy in the waters surrounding the larger islands. In 1929 it was my honor to determine for the Coast and Geodetic Survey values of gravity at 13 land stations in Porto Rico, Haiti, and Cuba. The following year an expedition known as the International Expedition to the Bahama Islands, under the auspices of Princeton University and directed by Professor R. M. Field, proceeded to the Bahamas. The study undertaken was the relation of the stability of the Bahama Block to the origin, migration, and alteration of the sediments deposited on the surface of the islands. The geologists, in studying the islands, realized the value and necessity of gravity-observations and requested the cooperation of the Coast and Geodetic Survey, with the result that I was detailed to accompany the expedition and make gravity-observations at six stations. The results were so interesting that the second trip of the expedition, made in February and March 1932, was entirely devoted to gravity-observations, both on land and sea. During this trip 12 land stations were established, making a total of 18 land stations on the Bahama Block. The U. S. Navy cooperated by assigning the submarine S-48 and its tender, the *Chevink*, to assist, and Dr. F. A. Vening Meines was again in charge of the gravity-at-sea observations.

The paramount factor in the success of the land expedition was Mr. Hugh M. Matheson's knowledge of the region and his ability as a navigator. He placed his yachts, their crews, and himself unreservedly at the disposal of the expedition, and also cared for the entire expense of the oceanographic part of the work. The yacht *Marmion* used for the gravity-work is an auxiliary yawl of 19 tons capacity and proved to be the ideal type of vessel for work in those remote localities where fuel becomes such a problem.

Inasmuch as it was so extremely difficult to land the gravity-apparatus, resulting in frequent handling, which called for a rugged field-instrument, the Mendenhall invariable half-second (quarter-meter) pendulum apparatus was selected. The observations were made in 9 by 9 center-pole tent. In cases where the islands were sandy and

low, concrete piers were built to support the pendulum receiver. However, ordinarily no difficulty was encountered in locating hard-coral masses to support the instrument. Due to the intense light during the day, a tunnel, consisting of heavy canvas wrapped around a frame three feet in diameter and six feet in length, was used. This tunnel was placed between the pendulum receiver and the flash-apparatus so that the coincidences of flashes of light could be observed. In the work in this locality it was found advisable to place a small amount of a dehydrating salt in the corner of the receiver, because if no salt were used there would be a question as to the exact pressure and conditions in the receiver. For example, without the addition of salt the receiver might decrease in pressure from 60 mm to 58 mm. This was probably due to expansion of the receiver and water-vapor in it. Under this condition, a question would arise as to exactly what had taken place. By the use of a dehydrating salt, this difficulty was at once overcome. During the night, temperature readings were taken every four to five hours, whereas during the day they were taken every hour if the rate of increase was appreciable.

Of the 18 stations observed in the Bahama Islands, 16 anomalies are negative and two are positive. The two most northerly stations showed positive anomalies. It is a most striking feature that the anomalies on the Bahama Islands are negative. A large majority of the island stations of the world show positive isostatic gravity-anomalies. Since most islands are formed of igneous rock, this is thought to be the reason for their positive anomalies. It is certain from the evidence of the gravity-observations that the Bahama Islands are not underlain by igneous rocks and did not originate as the result of submarine igneous activity. They are, without doubt, continental in character and closely related to the continent. There seems to be good evidence that the Bahama Block and the surrounding area are in isostatic equilibrium to a marked degree, and that the anomalies at several stations are probably due to abnormally light material close to the stations. During the course of the two submarine voyages mentioned previously, Dr. P. A. Vening Meinesz established sea stations surrounding the land stations and, with the aid of his gravity-data, showed that, in all probability, the Bahama Block is an old mountain system which has folded, eroded, and had its high tops cut off. In some cases these tops were probably eroded slightly below sea-level and sedimentation and coral-growth brought them to the surface as islands. The Tongue of the Ocean, Providence Channel, Exuma Sound, and other deep bodies of water in this region are eroded river-valleys. It is believed that the Bahamas are truly a sunken mountain system and continental in character.

The theory that the Bahama Block is in isostatic equilibrium, continental in character and relatively fixed, can also be substantiated by the gravity-data secured on the neighboring islands. The northern coast of Cuba was once under compression, but in an attempt of the tectonic forces to move the fixed Bahama Block the compression was retarded and block-faulting resulted. Then the islands of Haiti, Porto Rico, and the Lesser Antilles moved to the eastward, leaving these islands still under compression and showing signs of intense folding. A strip of negative anomalies exists north of Haiti and positive anomalies are found in Bartlett Deep, where depression and block-faulting result.

Wherever the crust of the Earth is dense, block-faulting or shearing results and in lighter material it is folded, depressed, and buckled. To illustrate this condition, let us assume two columns. The first is slender, and when compression is applied it buckles, bends, and folds. The other column is very massive or dense. In this case shearing will take place. The Bahama Islands, having negative anomalies, are therefore a folded system. Although the anomalies are of the same sign, they are rather local and the region as a whole is undoubtedly in isostatic equilibrium.

It is hoped that gravity-observations will be made in the Lesser Antilles in the near future in order to complete the gravity-survey of the West Indies, and thus make it the most complete and detailed gravity-survey of any country or group in the world.

U. S. Coast and Geodetic Survey,
Washington, D. C.

ISOSTASY AND RELATED SUBJECTS

F. A. Vening Meines

Gravity may give indications on two important problems. First, the way in which isostatic equilibrium is realized and, second, possible deviations from equilibrium. Before looking into these possibilities more closely, we shall consider our general knowledge about these problems.

The observations of gravity have shown that usually isostasy is approximately true. Vertical columns of the Earth's crust of a certain cross-section and reaching down to a certain depth, called the depth of compensation, contain the same amount of mass independently of where the column is located. This phenomenon is generally interpreted as a proof that the Earth's crust is in floating equilibrium on plastic lower layers.

This interpretation is in close agreement with current physical views about the constitution of the outer layers of the Earth. We must suppose that at a certain depth the viscosity becomes so low that the materials become plastic with regard to the slow movements occurring in geological processes. We shall not enter here into the question of whether this is a sharply defined limit with a sudden change of physical properties, or whether we have to regard it as a gradual transition.

If this interpretation is true, it is clear that isostasy cannot be perfectly local. The crust has strength enough to make it impossible for vertical columns of small cross-section to attain equilibrium independently of each other. We have to consider the crust as a floating structure with a certain strength with regard to shearing and compression and with a certain elasticity with regard to deformations below the strength limit. This crust has evidently been exposed to a great many agents and influences, such as erosion and sedimentation, temperature changes, chemical changes, melting, recrystallization, compressive and shearing forces, gravity, and others which have acted on it and deformed it through geological time and which have brought about the actual topography of the crust's surface. It is this history that determines what shape the crust has assumed and how the masses are distributed in it.

We shall accept as a normal part of the crust that part which is supposed to be undeformed and which reaches up to sea-level. The density is distributed equally in horizontal layers and increases downwards in a way as yet unknown. The thickness, likewise unknown, is comprised between 10 and 60 miles, probably between 20 and 50. The crust floats on a plastic layer of greater density.

We shall compare other parts of the crust with this normal part, calling the difference of mass in corresponding parts of both crusts anomalous masses, and the masses between the surface of the crust and sea-level topographic masses. Anomalous masses, according to this definition, may be negative and the same holds true for topographic masses, if we consider the sea as part of the crust.

If a portion of the crust is isostatically compensated, the sum of the topographic masses and of the anomalous masses in this portion is zero. In this statement, as well as in the further discussion, the Earth's curvature is neglected. The anomalous masses coincide in this case with what is usually called the isostatic compensation.

It has already been mentioned that the distribution of the anomalous masses is a function of the geological history of the crust of the Earth. Let us suppose, for instance, a part of the crust that was elevated above sea-level by some cause, which is supposed, for simplicity's sake, to have acted without disturbing isostasy as, for instance, density changes due to chemical action or temperature. This crust has been exposed to erosion and sedimentation, which have caused an irregular surface topography and we suppose that no secondary effects have taken place. In this case, we may consider the deposited materials as positive loads and the eroded masses as negative loads, both acting on the surface of the crust. This will cause a deformation of the crust, which we may assume to be of an elastic nature; it is unlikely that in this case the limits of strength will anywhere be exceeded. The crust will act as an elastic plate floating on a liquid on which loads are acting. It bends and in this way a shifting of mass is brought about which makes some of the masses anomalous

masses, because masses of different density take the place of the original masses. In these parts where the crust bends downwards, layers of less density displace layers of greater density and this leads to negative anomalous masses in these places. If, for instance, the crust at its lower boundary has a smaller density than the adjoining plastic layer, the downward bending causes negative anomalous masses at that boundary. Upward bending causes in the same way positive anomalous masses. It can easily be proved that the sum total of the anomalous masses, brought about by this elastic deformation, compensates the sum total of the loads acting on the crust. This means that the crust after deformation is still in isostatic equilibrium.

A similar situation comes into being when the upper layer of the crust is laterally compressed until folding and over-thrusting occur, while the main crust remains undeformed. An instance of this is found in the Jura Mountains. The combined over-thrusts act on the crust as a load and this again brings about a deformation of the above kind. When, somewhere, the stress exceeds the strength of the main crust, shearing may take place, giving a kind of vertical displacement of the crust other than that which a purely elastic deformation would bring about, but otherwise the principle, according to which isostatic compensation comes into being, remains the same. This kind of crustal deformation will, however, be exceptional, as it is difficult to imagine great differential movements between the upper and the lower strata of the crust. It can probably occur only in connection with a great crustal folding in the neighborhood, as in the instance of the Jura, the Alpine folding.

The great tectonic folding and thrusting which have taken place in the Alps and in other great mountain systems bring about an entirely different situation. Here, probably the whole Earth's crust is thrust together by huge compressive forces. It is fairly well known what has happened to the upper layers of the crust of the Alps: They have been folded and over-thrusted over distances estimated at many tens of miles. Four or more folds are found, one on top of the other. For details we must refer to geological publications.

Our geological knowledge, however, is restricted to the upper layer of the crust of a few miles thickness at most. It is entirely unknown what the main crust had undergone, save that it seems logical to suppose that it was subject to the same shortening as the upper layer. If the crust had had only slight strength we might have expected a crushing of the crust into a thickened mass, which--like a floating iceberg--would have a downward protuberance many times larger than the upward protuberance. The down protuberance would probably afterwards tend to be melted and flattened out, because it is thrust into regions of higher temperature.

What actually happens cannot be traced by geological evidence. We shall see, however, that gravity-research has given some indications about this matter and that these indications agree fairly well with the above supposition. If we assume it to be true, we should expect to find the compensation of the mountain system mainly concentrated in the downward protuberance, where light masses displace the heavier plastic layer. Irregularly distributed anomalous masses might further be expected throughout the whole system, the distribution depending on the way in which the crustal material has moved and displaced other material during the deformation.

It may be possible, although no conclusive evidence of it has been obtained, that occasionally the crust gives way in another manner to tangential compressive forces, namely, by shearing along a fault-plane extending through the whole crust. This will give rise to asymmetrical distribution of the anomalous masses, giving positive masses on the upward-moving side of the fault-some and negative masses on the downward-moving side. We shall not go deeply here into this possibility.

Nor shall we enlarge on the case of volcanic mountain formation. We have again a situation similar to the first case. The volcano acts as a superimposed load and the crust will bend down under the effect, causing, in this way, negative compensating masses in the crust and at its lower boundary. The question arises, however, where the volcanic material originates from and whether further transportation of material takes place in the crust. In that case, more bending of the crust upward or downward may take place.

The actual state of the Earth's crust will be a mixture of several of these and possibly other cases. It will be difficult to predict what the conditions are for certain parts of the crust. We may affirm that it is unlikely that a single system of distribution for the isostatic compensation could be found that would fit the facts everywhere even if we limit our consideration to the continental parts of the Earth's crust. Probably different conditions prevail in the oceanic parts of the crust and here our knowledge is still more fragmentary.

No single system of distributing the compensating masses in the Earth's crust being possible, we shall have to try different suppositions for different parts of the crust. By doing this we may determine which one best fits the gravitational field of attraction observed at the Earth's surface; but even if one of the systems fits well, we must be careful not to assume it to be the right one. It is a well-known fact that a certain field of attraction may be caused by an infinity of different mass-distributions and so we cannot go further in this case than to say that our assumption may perhaps represent approximately the true mass-distribution.

As a first approximation three systems may be mentioned, all of which have been applied. Each one is in harmony with one or more of the possibilities of mountain formation that have been previously mentioned.

The first system is the well-known Hayford-Bowie system of the U. S. Coast and Geodetic Survey; it assumes the compensation to be local below the topographic mass and to be distributed uniformly over a certain depth of compensation. This system would be in harmony with the process of mountain formation by vertical rise of the Earth's crust caused by decrease in density due to chemical action or rise of temperature.

The second system is the Airy system, applied, for instance, by Heiskanen in his isostatic studies, which also assumes local compensation but which concentrates it mostly or entirely in downward protuberances of the Earth's crust at its lower boundary. This system may approximate more or less closely the theory of the root formation in case of folded mountain chains, as outlined above.

The third system was proposed by the writer in the "Bulletin Géoédésique" of March, 1931. It assumes the topographic masses to be loads acting on an elastic crust floating on a plastic layer. The horizontal distribution of compensation is assumed to be proportional to the bending of the crust. Vertically, the major part of the compensation is conceived as concentrated at the lower boundary of the crust, while the lesser part is distributed over the thickness of the crust. This system is, roughly speaking, in harmony with topography, caused by erosion, sedimentation, volcanism, or folding of the upper crust layer.

The comparison of the observed gravity-field with the field which these systems of isostatic compensation would give or, in other words, the gravity-anomalies--according to these systems--will show how far they agree with the actual conditions. If there are deviations, they may indicate two different conditions. They may indicate that the distribution of the isostatic compensation is different from that of the assumed system, or the results may indicate that the crust is not in isostatic equilibrium.

For small areas these two possibilities cannot be distinguished. In fact, we mentioned already that we must not expect the isostatic equilibrium to be strictly local. Our third system of compensation takes this into account by giving to the compensating masses a more regional distribution than that of the topography. We shall not call this a deviation of isostasy, although the original definition of isostasy--the equality of mass in all vertical columns of the same cross-section--is no longer strictly true.

For slightly larger areas, as, for instance, blocks of a few hundred miles in extent, the answer to the question is more doubtful. It is difficult to decide whether an area of this extent can be held--and for a special instance is in fact held--out of its exact equilibrium position by the normal strength of the crust or whether special disturbing forces must be assumed to explain the deviation.

For still larger areas, for which we might venture as a minimum estimate a horizontal extent of 500 to 1,000 miles in all directions, one is in a better position to decide the question. There can be no doubt about the fact that such areas as a whole cannot show an appreciable deviation of isostatic equilibrium unless special disturbing forces are working, because the strength of the crust along the boundary would not be sufficient to maintain the deviation. To decide how far isostasy is true for such areas, we may simply take the mean of the isostatic anomalies; this mean value should be less than a few milligals if no disturbing agents are present.

Taking up this problem for larger areas, we have the advantage that we are no longer hampered by the difficulty that an infinite number of mass distributions are possible because they all fit the observed gravity field. It can be proved that for large areas the mean anomaly is practically determined by the sum total of all of the topographic and anomalous masses, at least, if these masses are confined to a layer thin in comparison with the horizontal extent of the area. If this total is zero--which is equivalent to isostatic equilibrium for the block as a whole--the mean anomaly is approximately zero, independently of the way in which these masses are distributed. When we apply another system of isostatic reduction this mean will not change appreciably.

Therefore, if the mean isostatic anomaly, taken over a large area, deviates appreciably from zero, we may be sure that there is a real deviation from equilibrium and that it is not caused by a wrong system of isostatic reduction. It is difficult to explain such widespread deviations. If the anomalies are positive and not very large, they might be explained by the presence of compressive tangential forces in the crust. These forces would give an upward resultant, which would bring the crust in a higher position than it would be in according to isostatic equilibrium and in this way they would give rise to a positive field of anomalies.

If R = Earth's radius, h = thickness of the Earth's crust, and s = tangential stress per unit of cross-section of the crust, the resultant upward force per surface unit is sh/R .

This would bring about an excess of mass, represented by the same formula. If d is the mean density of the Earth, the resulting positive anomaly would be $A = 2gsh/3dR^2$ and, in case the compression in the crust works in all directions, double this amount.

Another explanation of regional isostatic anomalies might be found in an abnormal pressure exerted by the lower plastic layer but it is difficult to see where this pressure could originate from.

Lastly we might think of a lag in adjustment after some disturbance has taken place, as changes of state in the crust, sedimentation or erosion, volcanic intrusions in the crust, deposition or removal of ice-sheets on the surface, etc. There are strong indications that the last case, for instance, occurs in Canada and in the countries surrounding the Baltic Sea, where thick ice-fields have been removed since the ice-age and where extensive fields of negative gravity-anomalies are found.

We come back to the first line of investigation, the study of the mass-distribution in the Earth's crust by applying different methods of isostatic reductions and by studying the way in which observed gravity differs from them. The study of the Bouguer anomalies, which represent the attraction by all the anomalous masses below sea-level, may also be worth while for this purpose. The knowledge of the mass-distribution will give valuable indications about the processes occurring in the crust.

One of the most important problems is the problem how folded mountain ranges come into existence. As has already been stated, geology gives no hold about the behavior of the main crust below the surface layer; gravity-investigation is here the only possible way of attack. The investigation may be made in existing mountain ranges but in this case our problem is complicated by the subsequent history of the region, as, for instance, the erosion and sedimentation, of which the effects complicate the original gravity-field. Clearer indications may be expected from the study of regions where the process is still going on. In this way by studying different regions we may perhaps be able to investigate the phenomenon in its different stages, as far as those stages can now be found on the Earth's surface.

Seismological, topographical, and geological evidence may guide us in planning this research. A beginning has been made by a gravimetric investigation of the Netherlands East Indies, and the two expeditions made possible by the United States Navy in 1928 and 1932 give valuable information about a part of the West Indian region. In both regions the surface evidence points to a process of mountain formation in an early stage. We shall not go into details here about the obtained gravity-results but we may mention the main outcome. In both cases a narrow strip of strong negative anomalies has been found bordered on both sides by fields of positive anomalies. It shows no direct correlation to the surface topography, although a certain parallelism to the lines of surface tectonic disturbance will be noticed. This independence of the surface features indicates strongly that we must regard it as the effect of a great phenomenon going on in the main crust of the Earth below the surface. The hypothesis that the main crust is buckling downwards along this line appears to cover the observed facts fairly well. This buckling would lead to the formation of a downward protuberance in these areas, which in this early stage of the process is not vertically below the multiple surface ridges, but if the process continues, the crust's movement would automatically concentrate these surface formations above the root. Thus, the final stage would be a mountain range isostatically compensated by a root below it.

Further research along this line is highly desirable. More complete evidence about this stage of the phenomenon may be found; other stages may be investigated by the study of other regions and so a more complete course of the process may be revealed. Besides this, the knowledge of the distribution of these lines of tectonic disturbance over the Earth's crust may be of the highest importance for understanding their cause. This may possibly lead to a better understanding of the forces working in the Earth's crust, which play a big part in the most important geodetic problem--the determination of the figure of the Earth.

Dutch Geodetic Commission,
Amersfoort, Holland

PROGRESS-REPORT ON RADIO DISSEMINATION OF THE NATIONAL PRIMARY STANDARD OF FREQUENCY

J. H. Dellinger

The national primary standard of frequency maintained by the Bureau of Standards is made available to the public by means of standard-frequency transmissions. These are given every Tuesday for four hours, on a frequency of 5,000 kilocycles per second. The primary standard is made to operate harmonic amplifiers which directly control the transmitting set used for the transmissions. The transmitted waves are held constant throughout each transmission within a few parts in a hundred million. At certain times of day and year, the frequency as received at a distance is observed to vary as much as a part in ten million. This is due to an effect equivalent to a Doppler effect in the ionized upper regions of the atmosphere.

The transmitted waves are received, and used as frequency-standards, throughout the United States, and occasionally in Alaska, Central America, and Europe. A new transmitter of greatly increased power is under construction to make the service more fully reliable. About the beginning of 1933 it is expected to have the improved service on the air five days each week. Additional frequencies will be used to insure reception of the waves at all times. This is a step toward the goal of a continuous service, available at all times and places.

U. S. Bureau of Standards,
Washington, D. C.

GEODETIC CONTROL FOR THE PLOTTING OF THE AERIAL
PHOTOGRAPHS OF THE BELCHER ISLANDS

Noel J. Ogilvie

With the extension of the Temiskaming and Northern Ontario Railway to Moose Factory (Mooseonee) on James Bay and the near completion of the new harbor at Churchill, 700 miles to the northwest, a knowledge of the coast-line and islands of Hudson Bay at once becomes of greater economic importance.

The history of early navigation in this great inland sea dates back a couple of centuries to the early explorations of the French and English. From rough sketches made by the early shipmasters, Hudson Bay was first represented on charts of that region. On the earliest charts several large islands were shown near the center of the Bay or in some cases close to the west coast. These islands evidently originated with Hudson's own chart of his voyage of discovery into the Bay in 1610. In the Journal of the voyage by Prickett (in Purchas, His Pilgrimes, five vols., London, 1625; Prickett's Journal is in Vol. 3) we are told that on leaving Cape Diggs on the north, the expedition southward bound for a more genial climate wherein to winter wandered about for three months in a labyrinth without end. From our present-day knowledge of the islands of Hudson Bay it is quite evident that the Belcher Island Archipelago was the entanglement which confused this intrepid explorer.

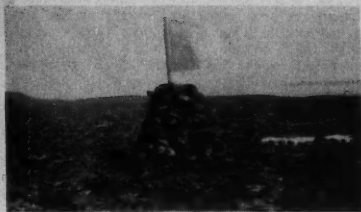
To Captain Coats, a noted shipmaster in the employ of the Hudson Bay Company from 1727 to 1751, must be given the credit for much of the topographical detail of the east coast and islands shown on the British Admiralty chart published in 1884. On this chart the Belcher Islands were shown as two groups, the north and south Belchers, the largest of them being not more than six miles in length. About 16 years ago a much more accurate representation of the islands was made by Mr. R. J. Flaherty, an American geologist, in the employ of Sir William Mackenzie at that time president of the Canadian Northern Railway. In 1914 and 1915 Mr. Flaherty with a small party visited these islands in a schooner and spent more than a year in investigating iron-ore deposits which had been reported to exist there. From rough compass-surveys and sketches obtained from native Eskimos he submitted in his report a sketch-map which has since been proved to be a fairly good general representation of the island group. This map shows the island archipelago about 90 miles in length and 45 miles in width.

Immediately following Mr. Flaherty's investigation and report certain commercial interests staked and leased from the Department of the Interior a number of iron mining claims on the Belcher Islands. Up to the present no development work has been undertaken. However, in recent years other commercial organizations undertook the staking of additional iron mining claims making it advisable to proceed with the mapping of the islands. Accordingly it was planned to carry out this operation in the summer of 1931.

Due to the short season suitable for survey work obtaining in Hudson Bay, it was decided to speed up the work by the use of aircraft. It was planned to establish a number of astronomical or triangulation control-stations at strategic points on the islands and at the same time to photograph from aircraft the entire archipelago using the principles and methods of oblique aerial photographic surveying. The establishment of the ground control was undertaken by the Geodetic Survey of Canada while the photography was to be carried out by specially trained pilots of the Royal Canadian Air Force.

On June 30 two pontoon-equipped planes took off from Moose Factory for the trip north carrying two engineers of the Geodetic Survey, their equipment, and two week's supplies. The engineers planned to land at some suitable point on the islands and proceed with the establishment astronomically of a local datum and the measurement of a base-line while the planes returned to Moose Factory for more equipment and also to complete arrangements for the delivery of a consignment of gasoline and supplies to the Belchers by the Hudson Bay Company's schooner Fort Churchill.

On leaving Moose Factory the two planes proceeded eastward and northward along the coast-line of James Bay and Hudson Bay but due to the prevalence of dense fog and bad weather several delays were necessary at points along the coast. On July 5 the



Geodetic triangulation-station



Mining claim corner-post



Namuktoo astronomical station



Immetalling astronomical station



Aeroplane on Belcher Islands



Native Eskimos' base-camp



Eskimo grave and skull, Belcher Islands



Kyak frame, Great Whale River

planes came droning over the trading-post at Great Whale River just as the local mission church was welcoming its Sunday morning congregation, comprised mostly of Indians and native Eskimos. Although aeroplanes were not entirely unknown to the people at this post, many of the natives had never seen aircraft before. Under the circumstances, the service was suspended and the congregation quickly assembled on the river bank to inspect the aerial visitors.

The following day proving bright and sunny, it was decided to make the 80-mile crossing to the Belcheres. From an elevation of 3,000 feet the islands were not immediately discernible due to haze and mist but after a half hour's flying towards the northwest they appeared as a dun-colored smudge near the horizon. Below in the icy waters of Hudson Bay large schools of white whales were seen, while here and there at scattered intervals small remnants of ice-pans floated, the last remaining evidence of grim winter's past regime. On reaching the vicinity of the Belcher Islands they were observed to consist of great irregular-shaped masses of bare rock entirely devoid of trees or shrubs. On the western side of the Archipelago could be seen an extensive ice-field extending as far as the eye could see to the westward. In places over the ice low-rolling masses of fog moved slowly about. In the succeeding weeks the personnel of the Geodetic Survey and the Royal Canadian Air Force detachment found it advisable to keep a wary eye on this ever-present menace to aerial activity.

From the air a suitable location was chosen for a base-line and triangulation base-net expansion. The geodetic party was landed nearby with their instruments, camp equipment, and food. The planes took off immediately for the return flight to Moose Factory leaving the engineers to commence the survey of the desolate wind-swept reaches of the Belcher Islands.

After a short preliminary reconnaissance a base-line and triangulation expansion was laid out. At one of the triangulation-stations a series of observations was made for latitude and longitude. John Ball's method of position fixation adapted to the prismatic astrolabe was used. In place of an astrolabe, however, a 5 1/4-inch theodolite was used with the telescope clamped at a fixed vertical angle of 60°. As aeroplane transportation necessitated a minimum of weight for instrumental equipment it was not feasible to carry a heavy astronomical telescope requiring adjustment in the meridian on a concrete pier. Considerable economy in weight was effected by using the small instrument which proved satisfactory for both the astronomy and triangulation.

John Ball's method of astronomical position-fixation, while not quite attaining the accuracy of the astronomical telescope-method, has been proved to give excellent results accurate to within one second of arc and hence well within the possible error due to the deviation of the plumb-line. A night's observation by this method consists of the observation of about 24 stars, six in each quadrant. Each set of four stars, one in each quadrant, gives an independent value of both latitude and chronometer-error. All errors due to incorrect readings of the circles are eliminated by this method. By using an electric chronograph together with a telegraph key the times of star-passages are recorded without appreciable error. A series of observations at Ottawa before and after the season's field work were made to determine the observer's personal equation. The determination simultaneously of the latitude and chronometer-error is a desirable feature of this method. In the northern latitudes of Canada, weather conditions are uncertain. Clouds roll up suddenly and obscure the stars which may not be visible again for a week or ten days. For this reason a speedy method of observation is required.

For the reception of time-signals in the determination of longitude a four-tube short-wave receiver was used. This receiver consists of one stage of untuned radio-frequency amplification, a detector, and two stages of audio amplification. Signals were received several times each day from Arlington and sometimes from the Dominion Observatory at Ottawa. The vernier clock method of reception was used permitting an accuracy in reception of 1/100 of a second of time. For the greater part of the season short-wave reception of time-signals was satisfactory and no serious difficulties were met with. In September, however, on the trip back to Ottawa an attempt was made to secure a position-fixation at Great Whale River on the east coast of Hudson Bay directly opposite the Belcher Islands. Due to brilliant displays of northern lights in the zenith, the short-wave radio failed to function for two successive nights. By employing a special hand-made plug-in inductance, signals from Arlington

on 2,656 meters were faintly heard at 3 o'clock one morning, coincident with vivid displays of northern lights. For longitude work in northern latitudes it is no doubt advisable to be equipped with both long-wave and short-wave receivers.

The measurement of a base-line involved no serious difficulties. As the location was very level it was possible to use a hand level for measuring the slope of each tape-length which seldom exceeded one degree. The most serious factor that had to be contended with in securing the proper accuracy was the prevalence of extremely high winds. It was found necessary to discontinue the taping operations on several days due to this cause. The base was measured with a 200-foot steel tape as well as with the 25-meter invar, thus precluding the possibility of making a bulk error in the measurement.

On July 21 the Fort Churohill landed a cargo of gasoline, oil, tent-poles, and supplies. A base-camp was established at Chimo Bay in the northern central area and about the same time two flying boats arrived to carry on with the oblique aerial photography.

Using the monoplanes for transport the triangulation-scheme was extended rapidly over the northern central area where the iron formation was known to exist. This triangulation of a secondary order involved lines up to about 15 miles in length. Daylight signals were used entirely consisting of a 7-foot length of straight cedar 1 inch by 2 inches in cross-section carrying a white flag at the top. Surrounding this target a stone cairn about $4\frac{1}{2}$ feet high was built. The triangulation-stations were marked permanently on the ground with bronze tablets cemented into the solid rock. For short lines or where the visibility was particularly good, pointings were made on the upright wooden signal. For longer distances pointings were made on the centers of the cairns. The triangular closures and side equations for this net show that the results are comparable in accuracy with the usual run of secondary triangulation.

In order that the control-points would be easily identifiable in the photographs a ground-mark was placed near each station. An 8-foot square of white cotton or whitewash proved sufficiently large for easy identification on the photographs. To permit orientation of the local topography near each station as plotted from the photographs a second mark was established where possible within a mile of the true control-station. By measuring on the ground the azimuth and length of the line joining the two marks considerable assistance was afforded in the plotting of the topography. To further ensure station identification in the photographs a few vertical aerial photographs were taken from an altitude of 5,000 feet showing the area near each control-station.

For the first time in the history of a Canadian Government survey expedition a portable radio-transmitter was carried which was operated by the personnel of the Royal Canadian Air Force. The transmitter, which was a single-tube oscillator rated at about 50 watts, was fed from the output of a direct-current generator directly coupled to a gasoline engine. The high-voltage plate-current was maintained in the neighborhood of 1,500 volts. Although not completely satisfactory, contacts were made every few nights directly with Ottawa. Of more importance still was its value in maintaining contact with the geodetic engineers during their operations at the outlying control-stations.

The north central area of the islands where mineralization is known to exist has been well covered by the triangulation-net. On account of the short season suitable for the safe operation of pontoon-equipped machines in this sub-arctic region it was not possible to project the triangulation-net to the extreme south of the Archipelago. An astronomical control-point was established, however, at "Mamuktoot" at the extreme south and at Inetalling at the extreme east. Should the mineral development of the islands in the future warrant the establishment of more control towards the south-western section it should prove an easy matter to extend the main triangulation-scheme in that direction. With the present number of control-points and the overlapping series of oblique photographs it will be possible to construct a map of quite a high order of accuracy. In future years if a geodetic triangulation-net is ever projected up the east coast of Hudson Bay it may be possible to connect it with the Belcher Islands scheme.

After landing at "Installing" to make the astronomical observations, the planes went back to the base-camp with instructions to return on the third day, the estimated day of completion. Although the observations had been finished on the second night, the third day proved foggy and not until the fourteenth day did the fog and rain clear up permitting the return of the planes. This incident emphasizes the necessity of carrying ample supplies of both food and fuel in order to survive such periods in a section of country where no vegetation is obtainable for fuel nor any natural food available except fish and seal which can seldom be procured without a boat or canoe.

The observations for latitude and longitude taken at a number of control-stations on the Belcher Islands show a discrepancy of about 30 miles in the position of the islands on existing maps and charts. A discrepancy of 25 miles in longitude was also found to exist in the location of the mainland coast at Great Whale River. The width of Hudson Bay at the latitude of the Belcher Islands is in reality about 25 miles greater than shown on our present maps and charts. It is very evident that the entire east coast of Hudson Bay is shown miles out of its correct position.

The Belcher Islands have, for a number of years, been known to possess extensive areas of iron formation. As no development work has been undertaken there yet, the concentration of iron in deposits sufficiently rich for commercial purposes has not been definitely proved. These rocky, treeless, wind-swept islands, involving an area 30 by 70 miles in extent, are entirely devoid of trees or shrubs except in a few places where a low-creeping willow is found. Lying about 60 miles off the east coast of Hudson Bay they form the home of 200 Eskimos. These people, a splendid type of native, exist almost entirely on fish, seal, walrus, and occasionally polar bear. Although only 800 miles from the capital city of Canada, comparatively few Canadians know of their existence. During February of each year, when the sea is frozen over to the mainland, a few of the more intrepid hunters venture across to Great Whale River to trade their white-fox skins for tea, tobacco, knives, matches, and other commodities. The women and children seldom journey farther than from one group of islands to another.

To the north of the Belchers, innumerable groups of smaller islands extend for a couple of hundred miles. Along the eastern coast in places, extensive island groups occur. The Hudson Bay area in general offers an extensive field for future geodetic-survey work.

Geodetic Survey of Canada,
Department of the Interior,
Ottawa, Canada.

ANALYTICAL METHODS IN AERIAL PHOTOGRAMMETRY

Earl Church

It is proposed to show in this paper something of what can be accomplished in the way of surveying by applying mathematical calculations to measurements on aerial photographs.

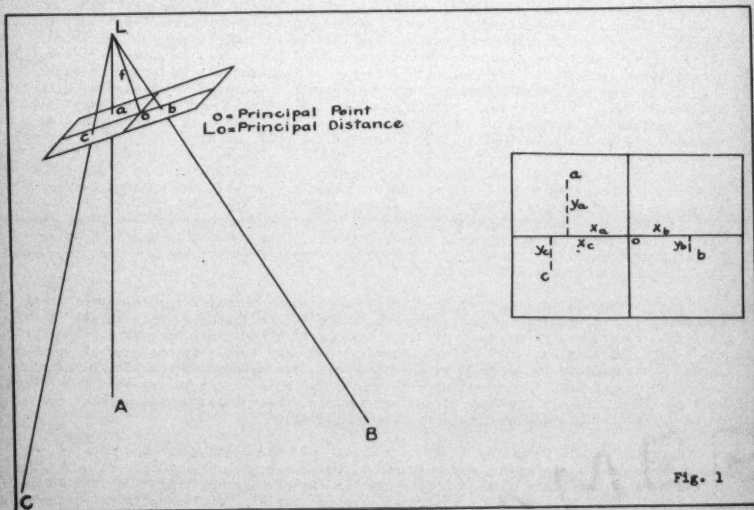
Possibly a few introductory remarks will serve to show the relation of the topic in hand to the entire subject of aerial surveying and mapping. Nearly every engineer probably has his attention called to aerial mapping first by the mosaic-map, with which everyone is by now to some extent familiar and concerning which so much has already been written, the scientific assembly of the aerial photographs themselves. Then one finds that this complete and faithful representation of the terrain obtainable in no other manner, is after all subject to certain errors, namely, those caused by the unavoidable and variable tilts of the camera-axis at the instants of the exposures and those caused by the displacements of the images in perspective due to the topographic relief of the ground, not to mention the failure of the mosaic to furnish any information regarding elevations of ground-points. Then one's attention is usually called to another distinct branch of the entire subject, namely, aerial photographic surveying, the methods of using aerial photographs as a substitute for the usual field work in ordinary surveying. In this branch of the subject there are three

different methods of attack: First, graphical methods of approximately determining horizontal locations of planimetric detail, without determining elevations, such as the radial-plotting method, the Canadian Government's perspective-grid method for oblique photographs, the method of using the photographs as an aid to plane-table work, and the methods of using them for revision of existing maps, all of which are highly valuable under certain specific conditions; second, the optical-mechanical methods of determining precisely both horizontal positions and elevations of ground-points by means of the stereoscopic-pantographic instruments of European manufacture; third, analytical methods.

In this paper there will be considered only the third method of attacking the subject of aerial photographic surveying, the analytical methods. An attempt will be made to tell something of how aerial photography offers a means of performing the complete field work of surveying, that is, determining the horizontal positions and elevations of any desired ground-points and furnishing all the data obtainable by the well-known terrestrial surveying methods. For accomplishing this, instead of mechanical processes by means of the complicated stereoscopic-pantographic instruments, we are to use mathematical computations by means of an ordinary calculating machine based upon the simplest kind of measurements on the photographs.

Throughout this discussion it will be assumed that the photographs are taken in the customary manner, as nearly vertical as possible, in parallel flight-strips with about 60 per cent longitudinal overlap between successive photographs and about 20 per cent lateral overlap between adjacent strips. Moreover, it will be assumed that immediately following the development of the original film negatives, contact positive prints are made upon glass plates upon which are made all the measurements considered in this paper.

Now there are several types of measurements on the plates upon which may be based the analytical calculations for photogrammetry. The most important are the ones made with a simple instrument called a comparator (see Fig. 6), designed to measure merely plane rectangular coordinates of images on the photographic plates, but to make these simple measurements very precisely.



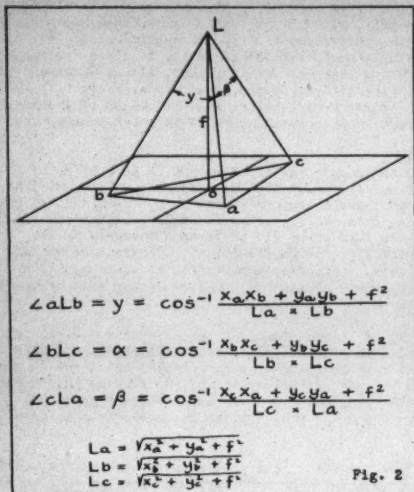


Fig. 2

The axes of reference for measuring the abscissas and ordinates of photographic images are the two rectangular axes indicated on the plate by marks within the aerial camera photographed directly upon the film or plate. The origin, the intersection of the two marked rectangular lines (Fig. 1), should be the foot of the perpendicular from the emergent node of the camera lens to the plane of the photograph. In the geometric figures of this paper the foot of this perpendicular, called the "principal point" of the photograph, is shown at the intersection of the two rectangular axes. The perpendicular distance from the rear node of the lens to the plane of the photograph is known as the camera principal distance. These so-called elements of "interior orientation" for the aerial camera should be accurately determined.

At this time attention should be called to the resources of these simple linear measurements of coordinates with the comparator, and the point made cannot be too strongly

emphasized. The only information regarding ground-points obtainable from aerial photographs consists of the positions of the images of the points on the photographs, and these positions are completely defined by simple x- and y-distances. Hence no data can possibly be obtained relative to ground-points by any method whatever, which cannot be obtained from mathematical calculations based upon these measured coordinates. When anyone hears statements about the seemingly difficult things which can be accomplished by means of stereoscopic-pantographic instruments, he should remember that these same results are obtainable by calculations emanating from simple rectangular coordinates. It is not to be maintained that analytical methods can compete with optical-mechanical methods in commercial work, but the analytical processes are extremely interesting nevertheless from a theoretical point of view.

Now of course in all surveying work positions of ground-points are given based upon some established datum. Two rectangular axes are established for the survey in the usual manner for giving horizontal positions. It is customary though not necessary to take some north-and-south line for the y-axis and an east-and-west line for the x-axis. Then this xy-plane is taken at sea-level or some other arbitrary fixed position as a datum for elevations. Positions of ground-points can then be given as three rectangular space-coordinates X, Y, Z.

Let us suppose that each of the aerial photographs contains the images of three so-called control-points, ground-points whose space-coordinates on this survey system have been determined by ordinary geodetic methods of terrestrial surveying. Now for the benefit of some who may be disappointed at the very outset in the possibilities of aerial photography on account of the fact that this assumption entails an enormous amount of ground work in connection with the aerial method, let me say that this point will be satisfactorily disposed of in due time. At present let us assume that the three control-points are available in each photograph.

The first plate is placed in the comparator and the rectangular coordinates of these three images are accurately measured. From these values of the coordinates the apex-angles of the plate pyramid L-abc shown in Figure 2 can be computed. The formulas, readily derived from the direction-cosine principle of solid analytical geometry, are

$$\cos \gamma = (x_a x_b + y_a y_b + f^2) / (L_a \times L_b)$$

$$\cos \alpha = (x_b x_c + y_b y_c + f^2) / (L_b \times L_c)$$

$$\cos \beta = (x_a x_c + y_a y_c + f^2) / (L_a \times L_c)$$

in which the plane coordinates of the three images are given their appropriate subscripts, f is the camera principal distance, and the lengths L_a , L_b , and L_c are obviously obtained from the expressions

$$\sqrt{x_a^2 + y_a^2 + f^2}, \quad \sqrt{x_b^2 + y_b^2 + f^2}, \quad \text{and} \quad \sqrt{x_c^2 + y_c^2 + f^2}, \quad \text{respectively.}$$

These three apex-angles are measured by the photograph just as really as if they had been read with a theodolite set up at the exposure-station.

Then the space-resection problem, or what might be called the three-point problem in space, is solved to locate the exposure-station in space where these three angles will be subtended by the three ground control-points (Fig. 3). That is, we find the space-coordinates based upon the survey datum of a point in the air where the three angles subtended by the ground-points will be exactly equal to the measured apex-angles of the plate-pyramid. This is done by solving simultaneously for X_L , Y_L , and Z_L , the space-coordinates of the exposure-station L , three equations which can be derived by analytical geometry,

$$\frac{(X_L - X_A)(X_L - X_B) + (Y_L - Y_A)(Y_L - Y_B) + (Z_L - Z_A)(Z_L - Z_B)}{\sqrt{(X_L - X_A)^2 + (Y_L - Y_A)^2 + (Z_L - Z_A)^2} \sqrt{(X_L - X_B)^2 + (Y_L - Y_B)^2 + (Z_L - Z_B)^2}} = \cos \gamma$$

$$\frac{(X_L - X_B)(X_L - X_C) + (Y_L - Y_B)(Y_L - Y_C) + (Z_L - Z_B)(Z_L - Z_C)}{\sqrt{(X_L - X_B)^2 + (Y_L - Y_B)^2 + (Z_L - Z_B)^2} \sqrt{(X_L - X_C)^2 + (Y_L - Y_C)^2 + (Z_L - Z_C)^2}} = \cos \alpha$$

$$\frac{(X_L - X_C)(X_L - X_A) + (Y_L - Y_C)(Y_L - Y_A) + (Z_L - Z_C)(Z_L - Z_A)}{\sqrt{(X_L - X_C)^2 + (Y_L - Y_C)^2 + (Z_L - Z_C)^2} \sqrt{(X_L - X_A)^2 + (Y_L - Y_A)^2 + (Z_L - Z_A)^2}} = \cos \beta$$

Although these equations are somewhat involved and their solution is somewhat difficult, yet this calculation like all others becomes simplified with the systematic arrangement of the work which one devises after much practice. This locates the exposure-station by determining its space-coordinates.

The next step is to orient the photograph with respect to the survey coordinate-axes. This so-called exterior orientation is given as three elements shown in Figure 4. The "tilt" is the angle between a horizontal plane and the plane of the photograph, or the angle between the camera-axis and a vertical line through the exposure-station. The "azimuth of the principal plane" is the survey-azimuth or direction from north, of the vertical plane passing through the inclined camera-axis. The "swing" is the direction on the photograph measured as an azimuth or the angle from the plate y -axis, "of the principal line," a line joining the principal point of the photograph to the nadir-point where the plane of the photograph is intersected by a vertical line from the exposure-station. These three elements orient the photograph, and together with the coordinates of the exposure-station actually fix the photograph in space. A method for computing this orientation, which was recently devised in our laboratory at Syracuse University, offers a considerable improvement over any method yet published.

In this new method the plate-coordinates of the nadir-point are found by solving simultaneously for x and y the two very simple linear equations

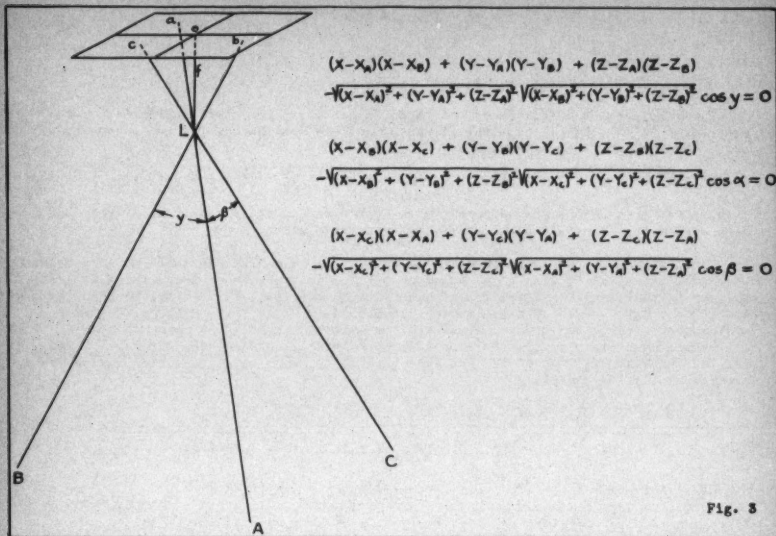


Fig. 3

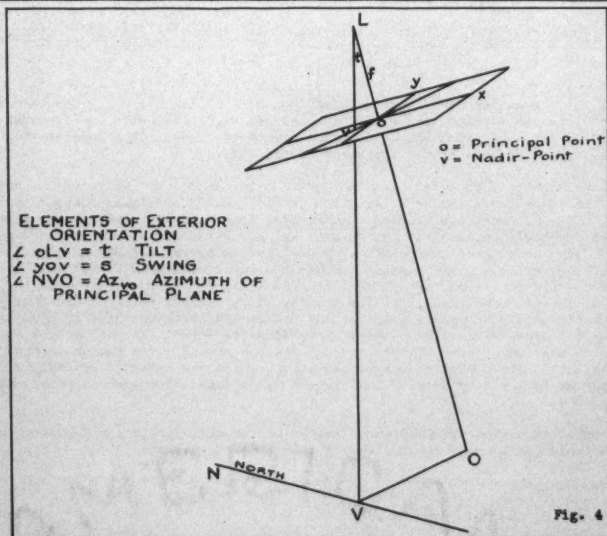


Fig. 4

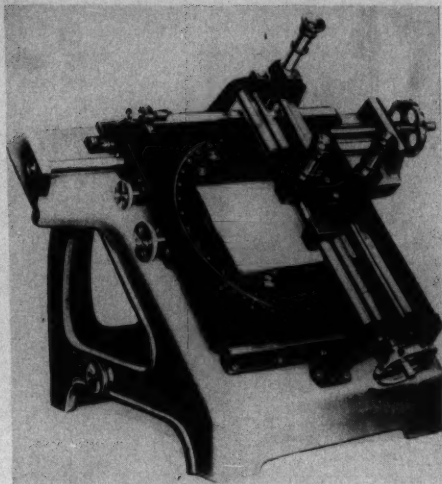


Fig. 6--Comparator

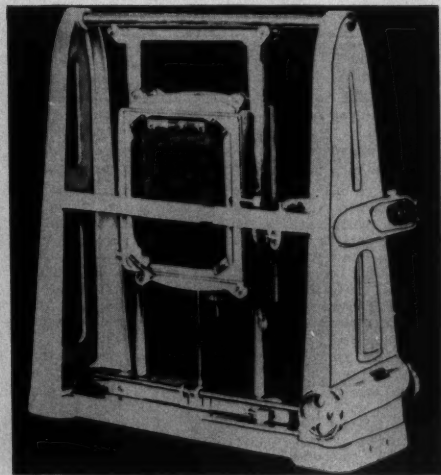


Fig. 7--Stereocomparator

If it is desired to determine the survey space-coordinates, horizontal position and elevation of some particular point on the ground, the two plates on which its image appears are placed in turn in the comparator and the coordinates of the image are measured. By means of the orientation data now available for each photograph, it is a simple matter to calculate from these coordinates the survey-azimuth or horizontal direction from each exposure-station to the undetermined point, and the vertical angle at each exposure-station measured from a truly vertical line to the direction to the undetermined point. The simplest way to do this is to orient each plate in the comparator so as to measure the image coordinates with respect to the nadir-point as the origin and the principal line from the nadir-point to the principal point as the y -axis, as shown in Figure 5. Then the azimuth or horizontal direction from each exposure-station to the new point is given by the relation

$$As_{LP} = As_{V0} + \tan^{-1}(x_p/y_p \cos t)$$

and the vertical angle at each exposure-station is given by

$$\tan m_p = \frac{\sqrt{x_p^2 + y_p^2} \cos^2 t}{(f \sec t - y_p \sin t)}$$

Then the calculation of the space-coordinates of the new point reduces to an ordinary surveying problem the horizontal position or the X - and Y -coordinates being found by the intersection-method using the azimuths from two known points, and the elevation being computed from the vertical angles. This entire process of determining new points might be called the problem of space-intersection.

It can readily be seen that this method as described fully constitutes a process of surveying. The space-coordinates can be found for any de-

sired point. As many points as are desired can be accurately determined horizontally and vertically on the survey-datum, to be used for any purpose whatever. If a map is the objective, as complete a map as is desired can be constructed from the data obtained, including the drawing of contours by interpolation in the usual manner between elevations determined.

These same results may be obtained from other kinds of measurements than the linear rectangular-coordinates. It will not be possible to enter into a discussion of all of them here. One of the most fascinating kinds of measurements is the stereoscopic measurement of parallaxes by means of an instrument called a stereocomparator (Fig. 7), using plates which have been subjected to "rectification," a photographic process with a special rectifying-camera for removing the effect of tilt. But the object of this paper is not to describe the more complex processes, but rather to show the possibilities in the application of a bit of mathematics to simple measurements.

Now if anyone investigates the ingenious stereoscopic-pantographic instruments of European manufacture, a few of which are now in operation in this country, in addition to their performing mechanically much of the work done by computation in the analytical method described above, one is impressed by the fact that ground-control is theoretically not needed after the first pair of photographs. With one photograph oriented in the instrument as to tilt, swing, and azimuth, the succeeding photograph is oriented without additional ground-control by a trial method of coincidence known as stereoscopic orientation. It was mentioned at the beginning that if anything is possible by the stereoscopic-pantographic instruments or any other mechanical method, the same thing is likewise possible by mathematical analysis based upon simple comparator-measurements.

This problem of eliminating control in the analytical method has been occupying much of our attention at Syracuse. Although for over a year we have had various analytical solutions for stereoscopic orientation, only recently has one been found which is at all practical. Our final solution is called the Four-point method. By means of this there can be calculated the coordinates of the exposure-station and the elements of exterior orientation for an aerial photograph by means of simple comparator-measurements of certain points on it and the preceding photograph, without the use of any ground control-points whatever. This eliminates entirely the necessity for any ground surveying except the determination of an initial triangle for the first photograph. Moreover, the method gives accurate results and is highly satisfactory in every respect. Although absolutely conclusive tests have not yet been made, it appears that control can be accurately carried forward through a flight-strip of very considerable length. Of course, after the exposure-stations and the orientations are calculated by this progressive process, then any desired ground-points can be located horizontally and vertically as before by the intersection-method. Thus we have an analytical method whereby surveying can be carried for long distances without ground-control. It provides a means for extending a survey over inaccessible country or over enemy territory in time of hostilities. It is indeed the ultimate problem in aerial photogrammetry.

This brief discussion is intended to tell something of the possibilities in the application of analysis to aerial photogrammetry. Of course, in this limited time no attempt has been made to develop the theory or to show in any detail how the computations are made.

In conclusion, it might be said that it is quite possible that the large, complicated, and very costly stereoscopic plotting-instruments, ingenious as they are, and representing as they do the climax in the progress in this subject to date, may not after all represent the ultimate method in aerial surveying. There still remains the possibility that analytical methods such as those which have been outlined based upon simple measurements of linear coordinates with a small and inexpensive instrument like a comparator, may eventually serve to bring aerial photogrammetry into more widespread use as a new and powerful means of surveying and mapping.

Syracuse University,
Syracuse, New York

TRANSACTIONS, AMERICAN GEOPHYSICAL UNION
NEW COMPARISONS OF THE INVAR WIRES OF MEXICO

Manuel Medina

(Translated by Earl S. Belote)

The geodetic bases of Mexico have been measured, since the year 1808, with wires of invar steel, 24 meters long, stretched in a free catenary and subjected to a tension of ten kilograms. The first base measured with these wires was that of La Cruz, in Tamaulipas, 40 kilometers long, and the results of this measurement were set forth in full detail at the meeting of the International Geodetic Association in Hamburg in 1912.

There followed the measurements of the Bermejillo and Colombres bases; the Yucatan, Sinaloa, and Lower California bases; and finally, the base at Aguascalientes.

The relative probable errors obtained in the measurement of these bases varied between 1:1,000,000 and 1:5,000,000. When the wires were first used there was encountered the difficulty of producing the tension without exposing the wire to a torsion force, which would undoubtedly produce a shortening. Various experiments made in our office showed us that, in order to use all the divisions of the wire it was necessary to eliminate the use of spring balances, employing instead a system of fixed weights attached to the wire and ball-bearing pulleys which could adjust themselves freely.

This Institution has eight wires, marked with the numbers 25, 26, 37, 31, 32, 33, 34, and 35, which were made by Carpentier and Demichel, in Paris, in 1904. The first three are those used on the La Cruz and subsequent bases until 1920, from which time the other five have been used also.

The original standardization of our wires was made at the International Bureau of Weights and Measures at Sevres, France, in 1905; and the computations of the first bases were made with the data furnished by that Office. At that time we were able to prove that the lengths of the wires remained unchanged, within the limits of the accuracy required for the measurement of a geodetic base, for their differences in length calculated with the field data gave practically the same results as those obtained in the laboratory.

Later, at the beginning of the measurement of the Colombres base, since eight years had passed since the original standardization, a comparison of wires 25, 26, and 37 was made at the Bureau of Standards in Washington. It was found that the first two had lengthened by about one-fifth millimeter and that the third had shortened by one-half millimeter. It was then supposed that the cause of the shortening of wire 37 was due to a permanent torsion which it had suffered in previous field work.

In the year 1920 the other five wires were sent to the Bureau of Standards in Washington. It was found from the results of this comparison that all of these wires had lengthened, with the exception of No. 32, the latter showing a shortening similar to that of No. 37.

Up to this time we considered the changes in the length of our wires as lengthenings which were a function of time, but upon using them on the Aguascalientes Base, after a lapse of five years, during which the wires had not been used, it was observed that there had been very appreciable changes in the lengths of the wires, some lengthening and others shortening, all of which made us think that there had been some change in their molecular structure.

The present article is written with the object of explaining the procedure which we used to make a new comparison of the wires used in the measurement of the Aguascalientes Base. It was necessary to know immediately the actual lengths of the wires used in order to compute the base, and so it was not possible to send them to the Bureau of Standards.

The comparison was made upon the length-comparator of our Office. A 24-meter section was measured with the geodetic standard-bar, which is four meters long. This bar has been used in the laboratory exclusively, for the standardization of the wires

of Mexico. It is of invar metal and has an H cross-section, and is equipped with a set of tripods and microscopes. Its constants have been determined in both Paris and Washington. Moreover, since it has not been exposed to transportation and to the inevitable rough treatment in field work, we supposed that there was a greater probability that it would have a constant length than in the case of the wires.

The length-comparator was installed in a passageway on the ground floor of la Direccion de Estudios Geograficos, which passageway is a little more than a hundred meters in length by two meters in width. Because of the isolation of this room from the rest of the building and the advantageous location of its doors and windows, it is possible to maintain a constant temperature during the day, with a maximum variation of one degree. On the floor of this room, strongly imbedded in masses of cement, are the bronze marks, at convenient distances for the direct comparison of the steel wires which the various official commissions used in their measurement work.

At one end of the 24-meter section, one of the microscopes was installed and leveled. Beneath it the bar was mounted in a horizontal position. At the other end of the bar the second microscope was set up vertically above the graduations and its immobility was assured by surrounding it with a platform for the observer. A series of simultaneous readings were made in the two microscopes for various positions of the bar. During this process temperature-readings were taken of the bar. The readings on the scale of the bar were taken to a hundredth of a millimeter and were considered to be in agreement when their respective differences did not vary from the mean by more than half a unit (five microns). After making several sets of readings, if these readings were in agreement, the bar was placed in the next position with the zero-end beneath microscope No. 2. The adjustment of the bar in azimuth and altitude was made without touching the microscope that marked the initial end of the section and taking care that the microscope which marked the beginning of the measurement was equally protected from any accidental movement whatsoever. The operation was then repeated, until the sixth section was measured, the end of which marked the final point of the whole measurement. The operation described took, normally, three hours.

Immediately afterwards the wires were successively compared with the section. They were put under a tension of ten kilograms and so placed that the divisions at the ends were beneath the microscopes; the scales on the wire were brought into focus by varying the height of support by means of an adequate movement of the tensors. When clear images of the scales were obtained, various sets of readings were made in the microscopes, with the position of the wire changed for each reading. Since these scales are divided in millimeters, the tenths of the division were estimated, and those pairs of readings were accepted which did not differ by more than half a unit (five hundredths of a millimeter) from the mean.

This operation was repeated for several days. Upon computing the lengths of the wires from the standardized length of the bar, we obtained lengths that were systematically less than those of the previous standardization, as if the wires had shortened. Considering only those wires used in the Aguascalientes Base, we obtained the data for the comparisons as in the following table.

Lengths of tapes reduced to temperature 15° C

Tape No.	International Bureau of Weights and Measures, France, 1905	Bureau of Standards, U.S.A., 1913 and 1920	Direccion de Estudios Geograficos, Mexico, 1931
25	24m + 0.81mm	24m + 1.03 mm	24m + 0.61 mm
32	0.86	0.69	0.60
34	0.70	0.99	0.73

These results surprised us for there was no way of explaining a shortening of the tapes which did not involve internal causes, interesting to investigate. But before going further, it was thought best to compare the geodetic standard-bar with some unit whose constancy could be controlled. This was done with greatest care immediately afterwards, using as the unit the prototype meter No. 25 of platinum iridium, which belongs to the Government of Mexico and is in the care of the Department of Weights and Measures under the Secretary of Industry, Commerce, and Labor. After taking the

official steps necessary to transport the prototype to our Office and compare it with our geodetic standard-bar, we were able to make the test, the details of which are interesting.

First, as the linear coefficient of expansion of the prototype is somewhat large--a little more than eight microns per degree Centigrade--it was necessary to construct a metal, double-walled case in which the meter was placed, supported on two metal rollers, perfectly protected from all external influences. Within the case there were two Centigrade thermometers, previously standardized, on which it is possible to estimate the temperature to 0.06. Small openings in the ends and center of the case covered with glass made it possible to observe the divisions engraved on the prototype and thermometers.

A beam of wood a little more than four meters long was placed upon two pillars of masonry and upon this five microscopes were mounted at intervals of one meter. Beneath these microscopes we placed the geodetic standard-bar, supported on its rollers. After the bar had been leveled perfectly, the microscopes were focused until the divisions on the bar could be seen with perfect clearness.

The standard bar was then replaced by the prototype in a trough of wood having the same form as the case for the standard bar. By moving the tripods of support, the divisions of the prototype were brought into focus, thus assuring the horizontal position of the prototype.

As soon as the thermometers showed a constant temperature, several sets of readings were made upon the divisions of the prototype by means of the micrometer-heads, whose values were determined with the measurements. Continuing in this manner each one-meter section was measured until the four were completed. These observations were made at different temperatures, from those near 0° Centigrade to the mean temperature of the comparator which was 19° Centigrade. To obtain the drop in temperature, cold water was circulated in the space between the double walls of the case which contained the prototype.

With this procedure we were able to measure the space between the end microscopes with an accuracy of two or three microns.

The geodetic standard-bar was again placed beneath the microscopes, and without touching these, but moving only the supporting tripods, it was brought into focus and a series of observations made upon the divisions.

The operation described was repeated twenty times, on different dates, and, as said above, under various temperature-conditions. There was also a frequent change of observers.

The result of this operation gave the length of the geodetic standard-bar at 17° Centigrade as

$$3.9999414 \text{ m} \pm 1.6 \text{ microns}$$

The old datum, as furnished by the International Bureau of Weights and Measures, was 3.9998807 m.

Our standard bar then had lengthened 0.06 mm in nearly 25 years and this change in its length is independent of use or mistreatment, for it has remained in the laboratory and has been used only under the most favorable conditions.

With this new value for the length of the geodetic standard-bar, the lengths of wires 25, 32, and 34 were recomputed with the following results:

Wire No. 25	at 15° C,	24 m + 0.96 mm
32	at 15° C,	24 m + 0.88 mm
34	at 15° C,	24 m + 1.07 mm

The differences between the new values and those obtained before the comparison of the standard bar have a mean of 0.36 mm; this quantity corresponds to the change in

the length of the standard bar, which was 0.06 mm, producing in 24 m exactly 0.36 mm.

As may be seen, wire 25, which has always been considered a good one, has shortened 0.07 mm with respect to its length determined in Washington in 1913, and on the other hand Nos. 32 and 34 have lengthened 0.19 mm and 0.08 mm, respectively, since 1920.

From what has been seen it is possible to deduce nothing definite in regard to the stability of invar, for even our geodetic standard-bar, which has been protected from rough usage and used in laboratory experiments only, has varied very appreciably in length, without it being possible to fix the law of this change.

The most prudent course, in order to continue the use of invar wires, seems to be that adopted by the U. S. Coast and Geodetic Survey, consisting of the periodic and systematic standardization of these tapes before and after their use in the field.

Dirección de Estudios Geográficos y Climatológicos,
Tacubaya, D.F., Mexico

PROGRESS-REPORT ON INVESTIGATION OF INVAR TAPES AND PRECISION-CIRCLES

L. V. Judson

(Publication approved by the Director of the Bureau of Standards of the United States Department of Commerce)

During the past year the Length Section of the Bureau of Standards has been co-operating with the Coast and Geodetic Survey in special tests of invar tapes with the aim of determining the mechanical or thermal treatment which will stabilize the invar base-line tapes used by the Coast and Geodetic Survey. This is part of a program of research at the Bureau to study the composition, heat-treatment, and mechanical treatment of invar which will yield dimensional stability. At present there are no definite results to report.

A new method of supporting the 50-meter base-line tapes when measuring along railroad tracks was used during the year by the Coast and Geodetic Survey. Supports were placed at the 12.5 and 37.5 meter points raising the tape at these points 152.4 mm (6 inches) above the rail, the tape at the terminal graduation (0 and 50 meters) being brought into contact with the rail during the measurements. This method of support was investigated at the Bureau of Standards and excellent checks obtained between the actual measurements and the theoretical values obtained from mathematical physical considerations.

Although not primarily of interest to the geodesist in his base-line measurements, a recent publication of the Bureau of Standards, Letter Circular 313, entitled "Nonomographic chart for use with steel measuring-tapes" may be useful to the geodetic engineer in some special measurements with tapes. Copies of this letter circular may be obtained on application to the Bureau of Standards.

A test of special importance in the field of precision-circles, made during the year, demonstrated the high accuracy of our circular dividing engine. A thoroughly-graduated 36-inch circle was graduated on the Bureau's circular dividing-engine. This circle was then carefully calibrated using several independent methods. The 720 half-degree lines are apparently in their correct position to one-half second or better and there is no periodic error in these graduations amounting to more than one-fifth second. A small systematic error, not exceeding a second was found in the subdivision of the half-degrees. It seems probable that this error can be readily eliminated from the dividing-engine.

Paralleling the tests of the Coast and Geodetic Survey relative to the use of solid silver circles, the Bureau has undertaken a program using castings of bronze and other alloys. Metal patterns designed so that the circles can be used in the 9-inch Parkhurst theodolite, are being constructed. Each step in the preparation of the

circles will be based on the best metallurgical and metrological practice. Modifications will be introduced when experiments indicate that improvements can be made.

U. S. Bureau of Standards,
Washington, D. C.

GEODETIC WORK ACCOMPLISHED FROM MAY 1, 1931 TO APRIL 30, 1932

William Bowie

As has frequently been stated at meetings of the Section of Geodesy of the American Geophysical Union, practically all of the field work in geodesy in the United States is carried on by the U. S. Coast and Geodetic Survey.

The branches of geodesy that are covered by that bureau's activities include the astronomical determination of latitude, longitude and azimuth, the measurement of base-lines, the observations of horizontal angles in triangulation, the observations of vertical angles for trigonometric leveling, the running of lines of precise leveling, the making of gravimetric surveys, and the observation at two field observatories of the variation of latitude.

The Coast and Geodetic Survey carries on other work which is of value in geodetic surveys, as, for example, the observations at tidal stations from which mean sea-level is determined. Again, the charting of the waters along the coast furnishes valuable data for making the reductions for topography and compensation at deflection-of-the-vertical and gravity-stations.

At the office of the Bureau, computations and adjustments are made of the field observations, data are prepared for publication, and certain scientific investigations are made which are based on the geodetic data collected.

The Coast and Geodetic Survey is cooperating with other agencies in the surveying and mapping of the country. It uses data collected by the U. S. Geological Survey, the Corps of Engineers of the U. S. Army, some of the larger cities, and by many other organizations that are doing work that measures up to the standard set for geodetic surveys.

The major geodetic operations are the extension over the country of arcs of triangulation and lines of leveling of first- and second-order accuracy. The triangulation is designed to furnish a strong framework of horizontal control. It connects surveys of the coasts of the country with those of the interior and thus the charts of the contiguous waters are correlated with the maps of the interior that terminate at the coasts.

The leveling-net is designed to furnish the basis for all surveying, mapping, and other engineering operations for which a knowledge of the exact elevation is essential.

Following the plan outlined by the Board of Surveys and Maps of the Federal Government, the Coast and Geodetic Survey is extending first- and second-order arcs of triangulation and lines of leveling over the country, with spacing of arcs and lines of about 50 miles. The intermediate areas will, perhaps, be covered by horizontal and vertical control of a somewhat lower order of accuracy but sufficient to meet the needs of topographic and other engineers.

During the past year arcs of first-order triangulation have been observed which cross, or touch, the following states: Texas, Illinois, Missouri, Iowa, Wisconsin, Minnesota, Montana, Wyoming, Colorado, Utah, New Mexico, Oklahoma, Nevada, California, Michigan, Virginia, North Carolina, South Carolina, and Georgia. The combined length of these arcs is about 3,500 miles.

One of the arcs completed during the year extends from the vicinity of Cairo, Illinois, to St. Paul, Minnesota. It was executed in cooperation with the Corps of Engineers, U. S. Army, a part of the field expenses of the work having been met by a transfer of funds from that organization to the Coast and Geodetic Survey.

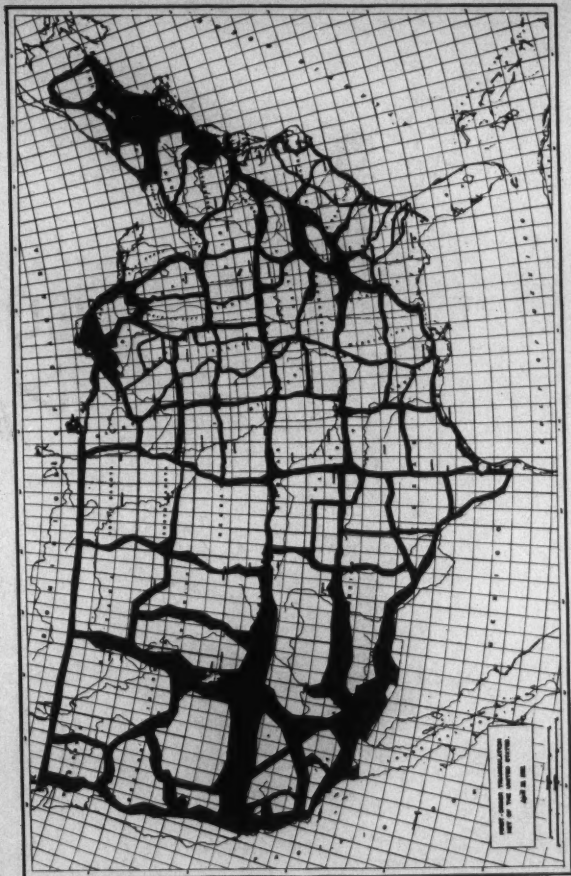


Fig. 1--First-order triangulation-net of the United States

The lines of first- and second-order leveling done during the year were in, or crossed, the following states: Washington, Oregon, California, Nevada, Montana, North Dakota, South Dakota, Minnesota, Wisconsin, Arkansas, Missouri, Texas, New York, Pennsylvania, Maryland, Delaware, New Jersey, Virginia, and North Carolina. The year's output of control-leveling in the states is about 6,000 miles.

The leveling from Philadelphia, Pennsylvania, to Lewes, Delaware, and from Wilmington, Delaware, to Havre de Grace, Maryland, a part of the year's work, was a cooperative project. The Corps of Engineers, U. S. Army, transferred funds to the Coast and Geodetic Survey to cover part of the field expenses, as was done to meet the cost of the arc of triangulation previously mentioned.

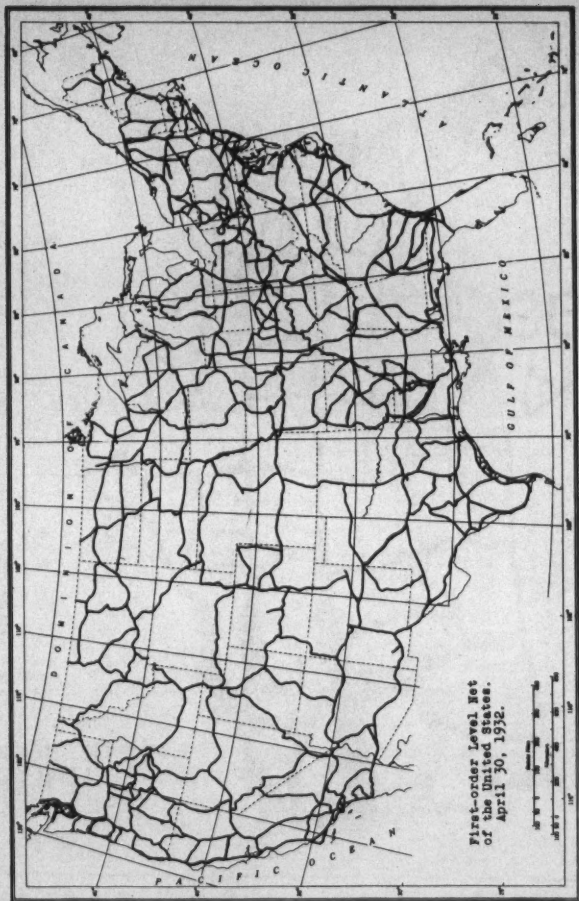


Fig. 2--First-order level-net of the United States

There are now about 34,000 miles of arcs of first-order triangulation and 65,000 miles of first- and second-order leveling in the United States, done by the Coast and Geodetic Survey and by other organizations. At the present rate of progress, the nets can be completed with the 50-mile spacing in about ten to twelve years. Whether the spacing of the arcs of control-triangulation and lines of accurate levels will be closer than this in the federal scheme will depend on the demands of the various government organizations and political subdivisions of the country.

During the year eight base-lines were measured in order to control the lengths of the arcs of triangulation. The aggregate length of these bases is about 80 miles.

More than a year ago the distance between two monuments, set at the ends of the pipe-line used by Prof. Michelson at Santa Ana, California, for the determination of the velocity of light, was measured by Mr. Clem L. Garner, Assistant Chief of the Division of Geodesy. The distance, approximately one mile in length, was measured with extreme care. After the resulting length had been furnished to Dr. Michelson, it was found that the velocity of light, determined by means of this tube, differed considerably from the velocity obtained when using the distance between Mt. Wilson and San Antonio Peak. It will be recalled that this distance, about 22 miles in length, had been determined some years ago by Mr. Garner. In deriving this distance every precaution was taken in transferring the length of a very carefully measured base-line, which is south of and parallel to the line between Mt. Wilson and San Antonio Peak, to the line joining those two mountains. It is believed that the airline distance between the two mountain points, used by Dr. Michelson, is correct within about one part in 1,000,000.

After Dr. Michelson died, the observations at Santa Ana were continued by Dr. F. G. Pease, one of the staff of the Mt. Wilson Observatory. Dr. Pease raised the question as to whether the measurement of the base-line beside the pipe-line might not be in error. No indication of serious error or blunder could be found in the records of the measurements made by Mr. Garner but, in order to make certain that the distance had a high degree of accuracy, a remeasurement of the distance between the monuments in question was made by Mr. E. B. Latham, an engineer of the Coast and Geodetic Survey, during the past winter. The preliminary value of the measurement by Mr. Latham differs from the value obtained by Mr. Garner by only 5.5 mm. It is possible that, when the restandardization of the tapes used by Mr. Latham has been made, the agreement may be even closer but, in any event, the difference between the Garner and Latham values given above is only about 1/300,000 of the distance between the monuments.

A vastly greater difference than that in the measurement of the Santa Ana base would have to be found in order to make the determination of the velocity of light at Santa Ana agree with the value obtained between Mt. Wilson and San Antonio Peak.

The variation-of-latitude observations were continued throughout the year at the station at Ukiah, California, and they were resumed about April 1 at the station at Gaithersburg, Maryland. Records of the observations made at these two stations are sent to Prof. Kimura, Chairman of the International Committee on the Variation of Latitude, whose address is Misusawa, Japan.

A single party made observations for the determination of gravity at stations in Virginia during the latter part of March and all of April. Another party was engaged during February and part of March in making observations for gravity at 12 points on certain of the Bahama Islands as a part of the work of the International Expedition to the West Indies, of which Prof. Richard M. Field of the Department of Geology of Princeton University is the Director.

All of the work mentioned so far has been done by the Coast and Geodetic Survey. One of the outstanding pieces of work done by other organizations was the determination of the value of gravity at 52 points in the waters of the West Indies and the Bahamas from the submarine S-48 of the U. S. Navy. The Navy Department cooperated by placing the submarine and the tender Chewink at the disposal of Prof. Field's expedition. Dr. F. A. Vening Meinesz, a member of the Geodetic Commission of Holland, came to this country in December 1931 with his multiple-pendulum apparatus and made the gravity-observations on the S-48. Dr. Meinesz had entire charge of the observations, and was assisted by Mr. Harry Hess of Princeton University and by Mr. Townsend T. Brown of the Naval Research Laboratory, Washington, D. C.

During the latter part of the work on the submarine, Mr. J. P. Lushene of the U. S. Coast and Geodetic Survey, who had made the observations on the Bahama Islands, assisted Dr. Meinesz in making observations on the submarine at four stations.

Supplementing the gravity-observations at sea in the West Indies and in the Bahamas, sonic soundings were made from both the Chewink and the submarine. These soundings gave very valuable information which will be useful in interpreting the

geological and geophysical history of the regions covered and will also be of value in the isostatic reduction of the gravity-stations.

Mention should be made of an important non-federal project in California. Mr. Floyd W. Hough, geodetic engineer with the Metropolitan Water District of Southern California, has during the past year or two extended 428 miles of first-order leveling and about 250 miles of arcs of first-order triangulation along the route of the proposed new aqueduct from the Colorado River to Los Angeles. Mr. Hough was, for several years, a member of the field force of the Coast and Geodetic Survey and has had wide experience in carrying on accurate leveling and triangulation. He has adopted, with slight modifications, the specifications for the triangulation and leveling as carried on by the Coast and Geodetic Survey. His work meets the high standards of the fundamental control-surveys and will be included in the national triangulation and leveling nets.

There is a growing interest on the part of city engineers in first-order triangulation as a means of controlling surveys and maps. Already several cities of the country have networks of first-order triangulation over their areas. Hartford, Connecticut, and other cities have made progress on surveys of this kind during the year.

Mr. Edwin J. Brown, a member of the field force of the Coast and Geodetic Survey, has continued his investigations involving rather radical changes in the methods employed in the field for making gravity-observations. The new apparatus was completed in February and Mr. Albert J. Hoskinson, another engineer of the Coast and Geodetic Survey, went to the field, about March 20, to thoroughly test the apparatus and the new methods. A number of stations in Virginia, not far from Washington, have been completed and preliminary reports from Mr. Hoskinson indicate that much better progress can be made with the new methods. It is expected that from 12 to 18 gravity-stations can be obtained in one month, as compared with four or five stations per month by the previous methods.

A new direction theodolite has been designed by Mr. D. L. Parkhurst, Chief of the Instrument Division of the Coast and Geodetic Survey, and has been constructed in the instrument-shop of the Bureau. This instrument has a horizontal circle of 6-1/2 inches and is almost a duplicate, as far as design is concerned, of the 9-inch direction theodolite designed by Mr. Parkhurst a few years ago. The new instrument has been tested in the field on second-order triangulation and has been found to be very effective. It gives accurate results with a small number of observations, is very rapid, and is very convenient to handle. At the time of writing this report, three additional theodolites of this design are being manufactured for the Coast and Geodetic Survey.

In extending triangulation over the more developed sections of the country, it has been found necessary to select most of the base-line sites along railroads. The measurements in the past have been made in the usual manner over stakes set along the right-of-way. Since the setting of the stakes requires from 25 per cent to 40 per cent of the base-measuring party's time, tests were made using the top of the rail as the tape-support with a view to materially reducing the time and cost required for preparing a base for measurement.

Measurements, especially those for traverses, have been made directly on the railroad rail with the tape supported throughout. There are serious objections to using this method for first-order bases as the adhesion of the tape to the rail under changing conditions of temperature and moisture is uncertain and the uncertainty in the temperature of the tape is greater under such conditions than where the tape is in the open air.

The method now adopted for measuring a base-line on the rail is to have the 0 and 50-meter marks of the 50-meter tape in contact with the rail, while the 12-1/2 and 37-1/2 meter points are raised about 6 inches above the rail by supports. When the tape is under tension, the middle point swings about 3/4 inch above the rail. The position of the tape is shown in Figure 3.

While all the details of this method of measurement cannot be given here it can be stated that the results over a test kilometer showed that it was practicable in

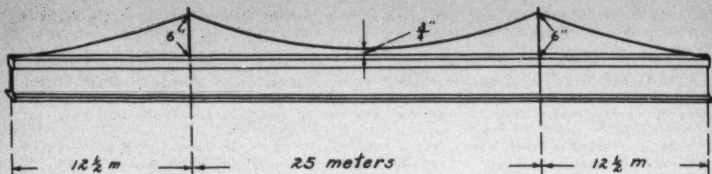


Fig. 3--New method of supporting tape above railroad rail

every respect and that it assured the high accuracy required in first-order base-line work. Subsequent base-line measurements when using this method throughout have all met the requirements satisfactorily.

The tapes are standardized at the U. S. Bureau of Standards before and after the measurements under the same conditions as they are used in the field.

No other important changes were made in any of the instruments or equipment used in geodetic work in this country. From the reports of the engineers carrying on the field work the instrumental and other equipment are of high grade and there appears to be not very much room for changes which would add to the efficiency of the work.

At the office in Washington an effort has been made to push to a rapid conclusion the adjustment of the triangulation- and leveling-nets of the country. The adjustment of the western half of the triangulation-net of the United States was completed some time ago and, at the time of the last annual meeting of this Section, the adjustment of the eastern half of the country was under way. That adjustment, as far as obtaining the most probable values of the latitude and longitude of the junction-points of the net was concerned, was completed in the autumn of 1931. Since then a number of sections of the net have been fitted in between the junction-points.

Within the last few months, Mr. Noel Ogilvie, Director of the Geodetic Survey of Canada, requested that an adjustment of the triangulation-nets of eastern Canada and of New York and New England should be made as a single unit. This request was complied with by the Director of the Coast and Geodetic Survey and the adjustment in question is now in progress. The most probable values of the latitudes and longitudes of the junction-points of this net will be available shortly after this report is presented.

Rapid progress has been made in fitting in the sections between the junction-points of the level-net of this country and, as far as practicable, the new lines of levels, run since the adjustment was completed, have been fitted into the existing net.

Some triangulation and leveling have been done in California with a view to laying the basis for the determination of earth movements, should an earthquake occur near an arc of triangulation or a line of levels. This special work was done in co-operation with the Advisory Committee in Seismology of the Carnegie Institution of Washington.

U. S. Coast and Geodetic Survey,
Washington, D. C.

FURTHER STUDIES ON THE LUNAR CORRELATIONS WITH SMALL CHANGES IN THE VARIATION OF LATITUDE

Harlan T. Stetson

Since the last report to the Section of Geodesy of the American Geophysical Union on "Further investigations of the moon's influence on latitude" (Pub. Nation. Res. Council, Trans. Amer. Geophys. Union, 12th annual meeting, 45-46, 1931), reduction of

latitude observations has been continued at the Perkins Observatory covering an additional 32,000 pairs of stars observed at Ukiah, Cincinnati, Gaithersburg, and Carlo Forte.

As it has become apparent that there is a tendency for a change in phase of the lunar correlation-curve, we have adopted the procedure of a careful comparison of these curves for the different stations made during the same intervals of time.

Periods selected have been divided into groups of three years, this being the interval deemed most advantageous from the point of view of selecting a sufficient amount of observational material and at the same time eliminating tendencies to change in phase exhibited if longer intervals are included.

On the assumption that there may be a lack of symmetry in the form of the lunar altitude-latitude curves from observations made when the moon is east and west of the meridian, the observations have been grouped by quadrants and show conspicuous differences in the altitude-latitude curves derived for lunar hour-angles east as compared with lunar hour-angles west. Marked differences are found between the Atlantic coast and the Pacific coast stations. The mid-continent station of Cincinnati shows the nearest approach to a sine-curve. It is thought that the differences in the forms of curves for the different stations may be due in part at least to the sub-continent structure, and therefore becomes of special geophysical interest.

Perhaps the most satisfactory presentation which can summarize the present status of this investigation is to be found from a set of graphs which have been drawn exhibiting correlation between the declination of the moon, the lunar hour-angle, and the variation in latitude for the four stations for the years 1909, 1910, and 1911. Three curves have been drawn for each of the four stations mentioned: One based on observations for latitude which were made when the moon's declination was south between the limits of -12° and -28° , a second comprising observations when the moon was near the equator, and the declinations varying between -12° and $+12^{\circ}$, and a third based on observations made when the moon was in north declination between the limits $+12^{\circ}$ and $+28^{\circ}$. In each case variations of latitude are plotted against the hour-angle of the moon.

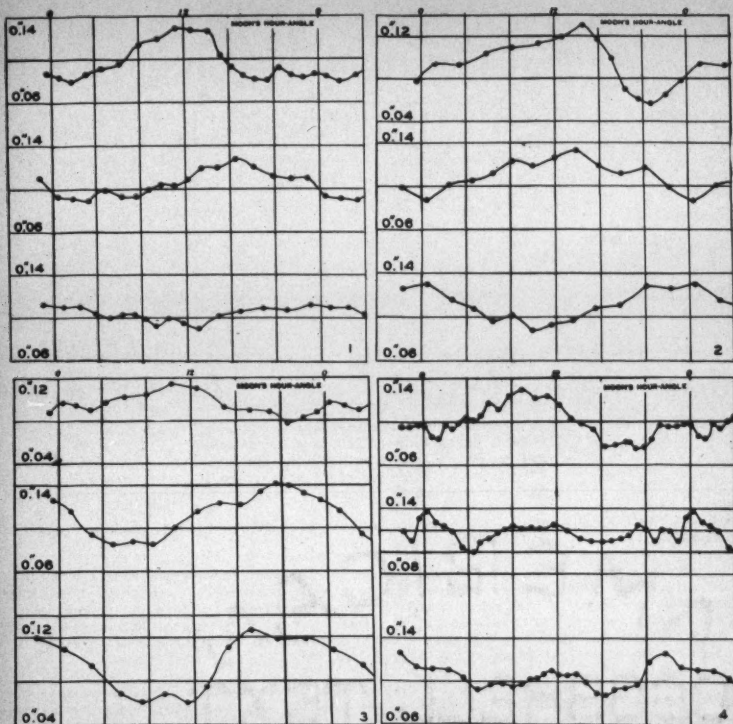
The curves plotting hour-angle against latitude variation all show striking similarity for case I, where the moon's declination for the observations in this group average 20° south. Here the curves approximate sine-curves with a maximum occurring in the neighborhood of 12 hours for the lunar hour-angle and a minimum at 20 hours. The rise from minimum to maximum consumes about 14 hours, and the fall from maximum to minimum about 10 hours. With slight variations at the different stations the extreme range in variation of latitude is 0.06 to 0.07 except in the case of Ukiah where the amplitude of the curve varies from 0.04 to 0.07 (1,374 pairs), the maximum range occurring at Cincinnati and the minimum at Ukiah.

In case II, when the mean declination of the moon is zero, the principal maximum of the curve is shifted to 16 hours in the case of Gaithersburg, 20 hours in the case of Ukiah, but remains at 14 hours for the Cincinnati observations. The amplitudes in this case range from 0.04 to 0.06, the largest range occurring at Ukiah (1,410 pairs).

In case III, where the moon's declination averages 20° north, the maximum of the curve shifts to about 22 hours. The amplitudes in this case are 0.02 for Gaithersburg, 0.04 for Cincinnati, 0.07 for Ukiah (1,113 pairs), and 0.04 for Carlo Forte.

A marked difference exists in the family of curves for the Atlantic coast station (Gaithersburg) as compared with the Pacific coast station (Ukiah) in one respect. There is a stated decrease in the amplitude of the curves for Gaithersburg as the moon moves north, ranging from 0.05 in case of average declination of -20° to 0.02 in case of average declination of $+20^{\circ}$, whereas at Ukiah the curves show a steady gain in amplitude as the moon moves north, the range being from 0.04 at declination -20° to 0.07 at declination $+20^{\circ}$.

The persistence of the same general form of curve in the case of all the stations appears to leave little doubt as to the reality of a lunar correlation. The fact that



Figs. 1 to 4--Correlation of lunar hour-angle with latitude variation and lunar declination for observations three years 1909-11 for Gaithersburg (1), Cincinnati (2), Ukiah (3), and Carlo Forte (4)--the upper curve in each case applies for declination -28° to -12° (case I), the middle curve for -12° to $+12^{\circ}$ (case II), and the lower curve for $+12^{\circ}$ to $+28^{\circ}$ (case III)

there is likewise a steady progression in amplitude with progressing declination of the moon appears added evidence for this conclusion.

It is apparent that any theoretical treatment of earth-tides must be extremely complicated, probably far more so than is the tidal theory for ocean-tides, on account of our nearly complete lack of knowledge of geological structure below the Earth's crust.

Since the apparent shift in the direction of the vertical referred to the stars appears to be several times greater than any shift in the vertical that seems permissible on the assumption of a theoretical earth-tide, the hypothesis is advanced that the apparent change in latitude with the change in positions of the moon may be best explained on the assumption of a minute shift in the land along the equipotential surface traceable to a luni-tidal cause. It is proposed to extend these investiga-

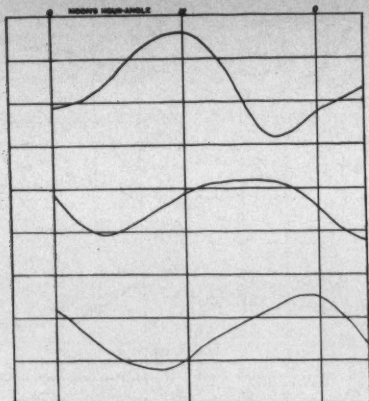


Fig. 5--Mean curves for all four stations, showing variations of latitude with moon's hour-angle and declination-groupings as for Figures 1 to 4--vertical scale, one division = 0.02

tions to cover all available data from all of the stations in the International Latitude Survey.

Acknowledgment is due the National Academy of Sciences for a grant from the Gould Fund to make possible these researches, and to Miss Frances Naylor, computer of the Perkins Observatory, for the careful and laborious numerical work involved in making the necessary reductions. Professor M. F. Jordan of the University of Maine has undertaken the extension of the reductions of the Cincinnati observations and has already completed the reductions of data for three years.

The importance of these tentative results both astronomically and geophysically leaves us to hope that additional latitude stations may be established in the southern hemisphere as soon as opportunity will allow.

Perkins Observatory,
Delaware, Ohio

AMERICAN GEOPHYSICAL UNION

Thirteenth Annual Meeting

REPORTS AND PAPERS

SECTION OF SEISMOLOGY

Washington, D. C.

April 28, 1932

CONTENTS

	PAGE
SECTION OF SEISMOLOGY	89
Symposium on the application of seismology to the study of ocean-basins. . . .	91
Seismology and the ocean-basins. W. H. Heck.	91
Accuracy of epicenter determinations. Frank Neumann.	94
Applications of interferometric tiltmeters in the problems of geophysics.	
George E. Merritt.	98
Seismology and structural geology. W. T. Thom, Jr.	102
Earthquakes in the North Atlantic as related to submarine cables. V. P. de	
Smitt.	103

SYMPOSIUM ON THE APPLICATION OF SEISMOLOGY TO THE STUDY OF OCEAN-BASINS

SEISMOLOGY AND THE OCEAN-BASINS

N. H. Heck

There are numerous types of oceanic investigation which have to do with the biology, physics, and chemistry of the oceans; with delineation of the submarine contours and otherwise meeting the needs of the navigator; with marine meteorology and terrestrial magnetism over the oceans; with variations in sea-level and the movements of the ocean-water. Many of these observations are made from aboard ship, whether from commercial vessels, or, more usually, from scientific expeditions. Geologists have tried to learn something about the great submerged area, but have had to depend chiefly on samples taken from the few upper inches of the ocean-bottom, or on investigations of the adjacent shores and of islands, especially oceanic islands. Therefore, many facts are lacking which would help in evolving entirely satisfactory theories of the origin of the ocean-basins and their present condition.

An important recent development has been the gravity-work at sea. This extension of gravity-work on land has been of special significance on account of the anomalies found in certain regions, notably the continuous belt of negative anomalies along the Dutch East Indies, which appears to be associated with earthquake occurrence in that region. My purpose in enumerating these different lines of attack has been solely to indicate just where the seismologists can fit into the program.

The seismologist has a different type of weapon from any other in this investigation. He cannot work from a ship, but he can place his instruments on any suitable island or place on the coast. The earthquake-waves which he records pass through the Earth and can, therefore, tell us much about an otherwise inaccessible region. Let us see what has already been done.

The principal belts of earthquake-activity have been well defined even if much is still to be desired regarding the accuracy of location of individual earthquakes. We know that these belts are places where intensive study by various methods is most likely to produce valuable results as soon as something definite is going on. We are also able to study general relations between submarine relief and earthquake-activity.

Geologists have established the fact that a granitic layer underlies the continents while the ocean-bottoms, especially the Pacific, are basaltic in character. The latter can only be inferred and the visual evidence is small. However, the basalt is denser and though the velocity of earthquake-waves would be reduced by increased density the accompanying increase in elasticity is such that the increase in velocity of the surface waves is on the order of 18 to 20 per cent greater than over entirely sub-continental paths. Angenheister has obtained the former figure from a study of records obtained at Apia, Samoa, while Neumann has obtained the latter from a study of Honolulu records.

Gutenberg has found that there is a considerable loss of energy as the surface-waves pass from the continent to the Pacific, but does not advance an explanation.

Gutenberg and others have distinguished between the Pacific and Atlantic basins, considering that the latter is in an intermediate condition between the continent and ocean as regards underlying material. Neumann and Leet, however, have found ample evidence of the same high-speed surface-wave, though it appears to have less energy than beneath the Pacific.

Seismologists are also interested in explaining microseisms and determining whether they are due primarily to water-movements or air-movements or both. They are also interested in studying the water-movements in the form of seismic sea-waves, which accompany earth-movements of certain types, with special reference to their significance in determining the movements in the sea-bottom. The collection of such data is now well organized by a commission under M. Hubert of France of the International Union of Geodesy and Geophysics. The collection of information for the coast of the

United States and the regions under its jurisdiction is being taken care of by the Coast and Geodetic Survey, and the United States Navy is also arranging to make reports on all tidal waves observed by Naval vessels wherever they may be. The arrangements have been made through a committee of seven of the American Geophysical Union, of which Harry Fielding Reid is Chairman.

Mr. Neumann will tell us some of the requirements which must be met if earthquakes are to be located and otherwise studied with the required accuracy. I do not wish to invade his field, but it is necessary for me to point out that for satisfactory location of earthquakes there must be a reasonable number of stations not too far away and correctly placed geographically. Accordingly, we are not going to get very far in the accurate location of submarine earthquakes until there are more stations on outlying islands and on portions of the coasts where there are no stations at present. The great value of a seismological station on an oceanic island is well illustrated in the case of Honolulu. While there are comparatively few strong earthquakes in the vicinity, Honolulu is in the center of the Pacific belt of activity with distances of from 3,600 to 8,000 km to all parts of it except that along the west coast of South America.

The best way to approach this problem is to consider the needs of a definite region. Since the Bahama-Caribbean region is now very much in the limelight and since it covers a wide range of conditions and since it is convenient to our shores, it is particularly worthy of seismological study at the present time. The Caribbean Sea is completely surrounded by a belt of earthquake-activity which is part of one of the major belts of the Earth. To the south we have the very considerable activity along the north coast of South America, in regard to which we have considerable information, though with a rather inaccurate character. The record extends over 400 years as is evidenced by the fact that the town of Cumana in Venezuela has been destroyed at least three times by earthquakes, the interval between the first and last known being more than 400 years, an occurrence which cannot be duplicated anywhere else in the American Continent. This activity follows the Windward Islands and then the greater Antilles to Eastern Cuba and Jamaica, then along the Bartlett Deep to Honduras and Guatemala. The western part of the loop extends through Central America and is of special practical interest because of the Panama Canal and the proposed Nicaragua Canal. Curiously enough there is considerable evidence that these two sites lie in the two least seismic regions of this belt.

In the northern part of the loop we note the sharp contrast between the considerable activity in the West Indies and the slight activity to the north in the Bahama group. While there are probably some earthquakes in the Bahama Islands, especially in the southern part of the group, there was only one for the period 1913-32, which was strong enough to be generally recorded and that was at the very southern end of the group. A similar relation exists between Western Cuba and Florida.

The region has some features in common with the Dutch East Indies which have been so carefully studied and it deserves equally adequate treatment. We are now obtaining excellent records from the Wenner seismometers at the Coast and Geodetic Survey station near San Juan, Porto Rico, and records should soon be available from the Huanayo Magnetic Observatory in Peru of the Carnegie Institution of Washington where two horizontal-component Wenner seismometers and a vertical Benioff seismometer have recently been established. The records from this station will prove invaluable, not only from the Caribbean region, but for the entire South Pacific. Good results may be expected from the Wood-Anderson seismometers to be installed at the Isthmus of Panama, though these are primarily intended for the study of nearby earthquakes.

There are now stations at Havana, Cuba; Kingston, Jamaica; Port-au-Prince, Haiti; and Port-of-France, Martinique. However, the station at Havana is not functioning and the others are having some difficulty in operation. It would be very helpful if these stations could be completely modernized. There is also need for additional stations at Nassau in the Bahamas and along the north coast of South America, preferably at Curacao.

Stephen Taber has called attention to the need for more intensive investigation of the Bartlett Deep and that part which lies between Cuba and Jamaica is especially convenient for investigation. To make the investigation complete there should be a

number of installations of short-period instruments at such places as Santiago, somewhere in Jamaica and Grand Cayman. It is also very desirable to have tilt-observations, such as are proposed by Mr. Merritt, in this region.

The Mid-Atlantic Ridge--My purpose is to call attention to the peculiar characteristics of this region rather than to advocate any plan of attack at the present time. In all other regions of the Earth where earthquakes are of frequent occurrence, depression of the bottom is the outstanding characteristic. Here the reverse is true and apparently the earthquake-cause is somewhat different. I quote from Washington who in turn quotes from Taylor the statement of a summary in regard to the ridge.

The persistence with which this feature maintains a medial position in the ocean bed for nearly 9,000 miles (following its great curves) is very striking, and the position which it takes in passing between South America and Africa is still more remarkable. The ridge is a submerged mountain range of a different type and origin from any other on the Earth. It is apparently a sort of horst ridge--a residual ridge along a line of rifting or parting--the earth-crust having moved away from it on both sides. On the chart it is indicated to be mostly less than 2,000 fathoms (12,000 feet) beneath the sea, with some parts less than 9,000 feet and a few volcanic islands which rise 3,000 or 4,000 feet above the sea. Its general height above the surrounding ocean-floor is between 3,000 and 6,000 feet, with a few island peaks rising 18,000 or 20,000 feet. Between South America and Africa the ridge runs southeast through 40° of longitude (nearly 3,000 miles), and in this part is parallel with the adjacent continental border of South America. It should be noted that there is no evidence of a deep trough on either side of this ridge. It should be noted that while practically all of the islands are of volcanic origin St. Paul Rocks is shown by Washington to be of deep-seated igneous rock. Washington discusses the significance and I mention it here only to point out the unusual and interesting character of the problems.

The large number of recorded earthquakes along the ridge is quite significant and many reports exist of earthquakes prior to the instrumental period recorded by passing vessels. The earthquakes of this ridge give an unusual opportunity to American and Canadian seismologists to study the time of travel of the surface-waves over Atlantic paths of considerable length, an opportunity not afforded to European seismologists because of the location of the ridge and the adjacent continents.

The precise location of earthquakes along the ridge is a matter of great difficulty. Stations are so few in the southern part that I will consider only the equatorial region and the part of the ridge to the north. There are a large number of high-grade instruments in Europe all at a considerable distance. The station in the Azores is close to the adjacent part of the ridge. The stations in Iceland, at Scoresbysund, Greenland, and those on the east coast of North America and Porto Rico are well located to give information. Stations at Nassau in the Bahamas and at Bermuda would constitute very important additions. While even this distribution is not entirely adequate and the location of many epicenters will be somewhat uncertain, the nature of the ridge is such that high accuracy is not as important as it would be in the case of a relatively deep and narrow trough.

The need for new stations and the improvement of existing stations where necessary is not so important in my opinion that an effort should be made to accomplish the purpose partially. The instruments should in every case be high grade; should be properly installed in suitable buildings; should be operated by competent scientific personnel and there should be adequate time-control. All these things cost money. However, it is believed that there are institutions at Nassau and in Bermuda at least, and possibly in Kingston, Jamaica, which could add this work to their activity just as the Huanacayo Magnetic Observatory of the Carnegie Institution of Washington has added seismological operations, and the desired result would be accomplished without undue cost. I would advocate, therefore, that the general policy be followed of establishing seismographs at already existing institutions, even if their general purpose is quite different. This plan accounts for the effective and wide distribution of seismographs in Japan.

While there is no immediate prospect of additional work on a large scale in the Pacific region this should not be omitted from consideration. The logical region for us to consider is the Alaska Aleutian region. It presents many difficulties, but these are not insoluble. At present the number of stations is rather limited. We

have Seattle, Vancouver, and Sitka on the east and Vladivostok, Tokyo, and Kobe with nothing between. The proposed station at Fairbanks, Alaska, will have McComb-Romberg instruments when it becomes possible to make the installation. The volcanological stations at Kodiak and Dutch Harbor will need additional instruments and personnel familiar with the subject before they can be considered as contributing to this problem, their present function being chiefly statistical in connection with volcanological investigations. Such a region presents peculiar difficulties on account of the few inhabitants and the lack of scientific institutions. The region has promising economic resources, especially the fisheries, and eventually there should be established a station of this type which could operate seismographs. A station at Attu Island would be particularly desirable. The program, well beyond any present resources, is not an expensive one and it should be capable of eventual accomplishment. Even if the necessary oceanographic investigations, especially the determination of bottom-contours, must be postponed indefinitely it would be very desirable to have additional seismological observations. This is practically virgin territory from the viewpoint of both oceanography and seismology and there is much valuable information to be obtained. There is probably nowhere on the American territory where the earthquakes are more frequent and severe than along the Aleutian Island Deep, though only the greater ones are at present recorded.

Seismology is a very comprehensive subject. It deals on the one hand with mathematical physics and on the other with engineering construction. The latter is probably the field in which it can furnish the greatest benefit. However, the study of the Earth itself is well worth while and men will not be satisfied until they understand the major features of its history. The key to that history seems to lie in understanding conditions in the region which I have discussed, which between them have most of the characteristics of the important earthquake-regions. If we could understand the formation of the Atlantic Ridge, the reason for the contrast in seismicity between the West Indies and the Bahamas, and the reason for the great Aleutian trough, it would no longer be necessary for the geologists to deal in generalities. However, it is likely that it will require the use of all the methods now available and the development of new methods before these problems will be solved. It is important to stress, however, especially in seismology, the time-element. The greater delay in starting the program the greater the delay in securing worth-while results. This is not the time to start great new undertakings, but it is the time to appraise the situation and prepare adequate plans.

In conclusion I wish to express my opinion that the collection of accurate data regarding earthquakes, particularly in those parts of the belts of maximum intensity which lie beneath the sea, is essential to the solution of ultimate earthquake-cause and earthquake-distribution. Many possible earthquake-causes have been suggested but none seem to meet the double test of explaining the differential stress in the Earth's crust which results in earthquakes and the location of earthquakes. Erosion and deposition provide an obvious cause of differential stress due to change in loading, and this can be an earthquake-cause, but it does not at all fit the distribution. The best thing to do at present is to collect accurate seismic, gravimetric, and other data, correlate them, and then preserve an open mind.

U. S. Coast and Geodetic Survey,
Washington, D. C.

ACCURACY OF EPICENTER-DETERMINATIONS

Frank Neumann

A discussion of the accuracy obtained in epicenter-determinations by instrumental methods involves (1) a statement of the accuracy to be expected at the present time, and (2) an explanation of the factors which control this accuracy.

There are several methods used in locating epicenters, the most commonly used method depending upon what seismologists know as the S-P time-interval used in conjunction with seismological tables. This interval affords a means of estimating the distance of an earthquake from any seismological station. When this information is

known for a number of widely scattered stations, it is a simple matter to locate the focus by swinging arcs on a terrestrial globe, or by using other available methods.

The S-P interval is the time-interval which elapses between the arrival of the high-speed compressional or P-waves and the slower-speed transverse or S-waves at any station. The interval increases with distance and is, therefore, a measure of epicentral distance. The relation between distance and the S-P interval cannot be calculated theoretically. It is based solely on empirical data. Compilations of this kind are the basis of our seismological tables, sometimes called travel-time tables.

Another method of locating epicenters consists in using only the first preliminary tremor and adjusting distances and travel-times for a large number of stations in such manner that the resultant travel-times form a smooth curve and all distances are consistent with a common focal point. Although the travel-times of the elementary waves are known fairly well, they are still a subject of lively discussion among seismologists.

When stations are less than 1,000 km from an epicentral area, the problem of estimating distance is somewhat simplified because the velocities of the elementary waves are uniform, or approximately so. There are other methods also but most of the investigations of today involve one or more of the three just mentioned.

Statement of accuracy now being obtained--One with experience in epicenter-work is reluctant to make definite statements concerning accuracy because so many factors are involved that every epicenter-determination presents a distinct problem of its own, in addition to problems common to all determinations. For the sake of consistency, however, the following summary may be taken as a working basis.

(1) In regions where local investigations are being carried on with specially designed equipment and all controlling factors are favorable, it is believed that epicenters are at times accurate within a mile or two (2 or 3 km). Five miles might better be taken as a more probable value. When such accuracy is attained, it is to be expected that analysis of the records also gives an indication of depth of focus. A knowledge of local geophysical constants is also to be presumed and the activities on the seismograms must be sharply defined. Studies of this nature have been made only in connection with relatively weak shocks. Among seismic regions covered in this manner are California, the Crimean Peninsula in the Black Sea, and Japan, although there is considerable divergence in the type of Japanese equipment as compared with that in the other two regions. Occasionally light shocks in Europe are located with a relatively high degree of precision because of the proximity of many high-grade stations. A program of intensive local research aiming at this degree of accuracy is also under way in the Mississippi Valley region.

(2) The next order of accuracy appears in the case of a group of stations lying within 1,500 km (1,000 miles) of an epicentral area. They must, of course, be well distributed around the area and should be more than 300 km away; otherwise depth of focus enters into the problem. We may expect an epicenter under these conditions to lie within 5 to 50 miles (10 to 100 km) of the true value, the accuracy depending again upon the distribution of stations, quality of station equipment, and quality of instrumental records. The outstanding advantage of instrumental control in the zone under 1,500 km is that discrepancies in the various seismological tables are less than in any other zone.

(3) When accuracy depends upon results from stations at distances greater than 1,500 km, with possibly a station or two inside that zone, we may expect errors to range roughly from 15 to 200 miles (25 to 300 km), the greater divergences being due to distribution and efficiency of stations, clearness of records, and, it should be emphasized, to uncertainties in travel-time tables.

Discussion of factors which control accuracy of epicenter-determinations--The factors which control the magnitudes of the discrepancies just mentioned will be discussed in detail in the following order: (1) The distribution of seismograph-stations; (2) the class or efficiency of stations; and (3) uncertainties in our knowledge of travel-time phenomena for seismic wave-propagation.

The distribution of stations about an epicentral region is a particularly important factor because a desirable distribution will often offset the effect of inefficient stations and uncertainties in travel-time. We must accept certain errors in estimations of distance as inevitable. The best we can do is hope that a favorable distribution of stations will effectively compensate them. If the stations all lie in one general direction from an epicenter it is obvious that because of slightly incorrect distances the intersections of arcs drawn about them will define an elongated epicentral zone in which the focal point will be reasonably well defined in one direction only. To correct this it is necessary to have stations distributed so that the arcs will intersect nearly at right-angles. But this alone is not sufficient. Suppose, as we often find, that our travel-time tables do not fit the data well, as may be indicated by inability to compute a common time of origin. This means that our distances may all be too great or too small, and the only practical solution is the maintenance of stations on opposite sides of an epicentral zone. This affords a check on the travel-time characteristics which are peculiar to any given earthquake or region.

Regarding distribution of stations with respect to distance, it can be seen from a study of the uncertainties apparent in travel-time tables that they are smallest when the distances are less than 1,500 km. They are greater beyond this distance but remain roughly the same from 2,000 km up to 9,000 km. Beyond 9,000 km the Earth's core splits up the elementary waves to such extent that it is not desirable to use the data in epicenter-work. In view of these facts the aim in mapping out a program of seismological work should be first to establish as many stations as possible within 1,500 km of the seismic region, and secondly, to distribute them as uniformly as possible on all sides of the zone.

There is another problem connected with distribution of stations which bears possibly a little more on the research problem than on the problem of accurate epicenter-determinations although they are both so closely related that no distinction ought to be made. Investigators are attacking the fundamental problems of seismology through the medium of the travel-time curve. The study of transmission-times is probably given more attention than all other seismological investigations combined. The seismologist's aim, therefore, in his attempt to improve present-day seismological tables, is to develop accurate travel-time tables for individual earthquakes over the full range of distances from 0 to 9,000 km or more. The unfortunate facts are that the distribution of data over this distance for any one earthquake is just as irregular as the distribution of seismographic stations over the surface of the globe. So when it comes to comparing the transmission characteristics of different earthquakes, the investigator is left high and dry for lack of data which only a more uniform distribution of world stations will ever overcome. For the time being he must be contented with piecemeal information.

The second important factor in epicenter-accuracy concerns the efficiency of seismological stations. It is necessary here to mention only some of the problems which are outstanding in so far as they directly affect epicenter-work. Suppose that by some miracle a satisfactory distribution of stations throughout the world could be realized. Would the transmission data then solve the travel-time problem? Only if the stations were efficient and that means, for one thing, that both high- and low-magnification installations are essential. Experience teaches that if a shock is strong enough to be well recorded at distant stations the records are lost at nearby stations because of excessive movement of the recording points. If good results are obtained near the epicentral zone the shock is then too weak to be well recorded at distant stations. Inside the 1,500-km zone it is the usual experience in the case of heavy shocks to lose all but the first movements, and on many teleseismic records much data are lost because of excessive sensitivity of the seismometers. For ordinary teleseismic work it is doubtful whether seismographs magnifying more than 500 times are desirable.

Accurate time-control is a prime requisite for a first-class station. It has just been stated that very often in epicentral regions only the first impulses are recorded. When the remaining portions of the records are lost the seismologist is dependent exclusively on the accuracy of a station's time-control in estimating epicentral distance. As an error of one second in time corresponds to an 8-km error in distance, this is a vitally important factor. Radio time-signals have to a large extent solved the problem of obtaining correct absolute time, but other sources of inac-

curacy are to be found in irregular rotation of recording drums and unsatisfactory time-scales on the records. Average deviations of one-half second and occasional deviations of several seconds are to be expected when measuring time on a gram of an average first-class station, or stations often listed as first class.

Perhaps the most difficult problem which arises in the determination of epicenters lies in the inaccuracy or rather incompleteness of our seismological tables. At the shorter distances it is not quite so serious as at distances beyond 1,500 km, but even at the shorter ranges there is much to learn, especially in the identification of phases.

Within the last few years travel-time tables have been published by the late Dr. Turner, Gutenberg, Jeffreys, Macelwane, Visser, and others. No two are exactly alike. They cannot all be right and it is doubtful whether they are all wrong. As in other problems of this nature in the realm of physics, it will probably be discovered some day that all were partly right and partly wrong. We are not clear on why the tables are in error when our arc-intersections are bad or why the tables are correct when the intersections are good. Our object at the present time is to discuss the magnitude of the discrepancies between these tables.

If we confine our attention to differences in the important S-P interval we find in the upper range of the 1,500-km zone discrepancies corresponding to 40 and 50 km. These are due largely to the initial velocities adopted in the tables, and it now seems quite certain that they are not the same in all parts of the world. The initial velocity of the compressional wave, for instance, ranges from 7.4 km to over 8.0 km, a difference of nearly 10 per cent. This affects both the S-P interval at the shorter distances and also to some extent at the greater distances. If there are three or four good stations within the 1,500-km zone, it is possible to arrive at a fairly accurate value of regional velocity and the resulting error in epicenter-determination becomes only a fraction of what it would otherwise be.

In the teleseismic zone, from 1,500 km to 9,000 km, the maximum differences in the S-P intervals correspond to 200 km or more. If an average value of the interval is used this figure will naturally be reduced one-half, but it is serious enough at that. It is unfortunate that usually the great majority of stations lie in this zone. The discrepancies in the tables may be due in part to (1) abnormal variations in the structure of the more shallow layers of the Earth beneath epicentral areas, (2) to variations in focal depths of earthquakes, and (3) to uncertainties in theories concerning seismic wave-transmission.

Abnormally high- or low-velocity structures in an epicentral zone undoubtedly have an effect on transmission-times at great distances as well as in the epicentral zone, but at this writing we can only conjecture as to the magnitude of this effect. We do not find any general attempt to correct travel-time tables with respect to paths followed although some excellent work has been done in this respect for earthquakes in the South Sea Islands.

Regarding the effect of focal depth on travel-time, we find from theoretical considerations alone serious departures at both nearby and distant stations. In practice it is difficult to estimate depth of focus--in the great majority of cases impossible. It is only rarely in Japan, for instance, that focal depths have been closely determined by several different methods. Work along this line is developing satisfactorily in southern California also, but in the great majority of cases we know nothing very definite of the effect of depth on transmission-times. Some attempts have been made to develop tables which take into account various specific focal depths within the crustal layers, but it cannot be said that they have solved the problem. It is simple enough to obtain a reasonable depth of focus on the basis of some theory but the difficulty comes in proving it. Unless some of the theories advanced in recent years stand the test of proving invariably consistent, the actual effect of focal depth on transmission-time will still stand as an unsolved problem.

If we are to accept deep-focus earthquakes as genuine, that is, foci reaching depths of 300 to 400 km, then our generally accepted average values of travel-time must be put aside entirely and special tables developed for this type of shock. Either the deep-focus earthquake is an actual fact or there is something fundamentally wrong

or missing in our interpretation of seismic wave-propagation. One may feel more or less at liberty to criticize the investigator who explains certain observed activities in a complex record as being deep-focus effects, but when the very first activity, the so-called P or P' wave, appears on an undisturbed trace at an abnormally early time the seismologist is hard put to explain it on any other basis than a deep-focus effect.

This brings us to the remaining factor, namely, that we cannot be too certain that our present understanding of seismic wave-propagation is correct. Elementary compressional and distortional waves are not elementary in the sense that they are wave-groups of unbroken sinusoidal character. On the contrary they are extremely complex indicating that the activities which crowd one another in rapid succession in the first train of waves must follow different paths.

It is important to note that these activities occur within a time-interval which represents approximately the zone of apparent travel-time variation. Some investigators have attempted to label them with subscripts, such as P_1 , P_2 , etc., but no definite explanation is given which might provide a means of deriving more accurate epicenters by the usual methods.

An interesting point in connection with the broader aspects of seismic wave-propagation is developing in connection with a study now in progress of the recent Santiago earthquake. Ordinarily when travel-times are plotted graphically, we expect the curves to be reasonably smooth. In the Santiago shock this so-called curve is developing as a series of straight lines which, if smoothed out, would give us a standard curve. The significance of this is that if the straight lines are genuine the waves travelling through the interior of the Earth would follow the surfaces of discontinuity instead of curved paths which are concave outward. In other words, it seems possible that the waves in the deeper portions of the Earth follow the same laws of propagation suggested by Jeffreys for waves in the surface-layers, that is, a large portion of the wave-energy is propagated along surfaces of discontinuity. It would not be unreasonable to expect that interior waves may be propagated in both ways, (1) along surfaces of discontinuity, and also (2) by continuous refraction through the various shells of the Earth.

In reviewing the problems involved in the accurate determination of epicenters, it should be borne in mind that seismology is one of the youngest of the modern sciences. This paper does not pretend to cover all the problems but enough has been stated to show that seismology is not yet at its zenith as a precise science. The great need today is the accumulation of sufficient empirical data to establish the exact nature of seismic phenomena and seismic wave-propagation. The development has already reached the stage where practical results under favorable conditions can be assured, and we may expect greater precision with less effort as the science advances. If it is reasonable to assume that the endless variations in types of seismographic records are due to variations in the nature of individual earthquakes and to regional geophysical factors, then certainly we should consider seismology a fertile field for further investigation.

U. S. Coast and Geodetic Survey,
Washington, D. C.

APPLICATIONS OF INTERFEROMETRIC TILTMETERS IN THE PROBLEMS OF GEOPHYSICS

George E. Merritt

(Abstract)

It is my purpose at this time to describe very briefly a method of measuring small changes in orientation of any large mass with respect to the direction of gravity, and also to examine in some detail some of the applications of such a method to the investigation of several problems of importance to the advance of the science of geophysics.

A description of the instruments which I have so far used in my investigations of the practicability of using this method in the solution of geophysical problems is not

of very great importance. They are in the process of development and will almost certainly be greatly changed to meet special conditions and unforeseen contingencies. The method, however, will remain fundamentally the same.

Theory--Two optical planes are placed close together and nearly parallel, one of which remains at the same angle with the direction of gravity while the other is fixed with respect to the mass to be examined. In the instruments so far, the two planes have been nearly normal to the direction of gravity, that is to say, nearly horizontal, but this is not a necessity of the method.

Method of reading--A circle of suitable size with two diameters at right-angles is inscribed on one of the reflecting surfaces of the interferometer, and these are oriented north-south and east-west. The difference in number of fringes crossing the north-south diameter before and after a tilt has taken place serves as a measure of the north-south component of the tilt. Likewise, the east-west component is obtained as the difference in number crossing the east-west diameter.

Sensitivity--It has been calculated that for a circle 6.06 cm in diameter, one fringe-difference in the number of fringes crossing a diameter would indicate a tilt of one second in that direction. Since one-tenth of a fringe may be estimated, an instrument of this size may be said to be sensitive to one-tenth of a second. In order to obtain the sensitivity of Ishimoto's horizontal-pendulum instrument, a vertical pendulum or liquid free-surface instrument would have to have a circle 12 cm in diameter. An instrument of this size would be by no means difficult to construct and its inherent accuracy would not be impaired by the increase in size; however, my experience so far leads me to believe that smaller instruments will prove more serviceable.

Method of measurement and types of tiltmeters--The problem of measuring the tilt of any large mass divides itself naturally into two parts, (1) an instrument which will measure the tilt of the surface on which it is set, and (2) a method of installation which will insure that this tilt really indicates the tilt of the mass as a whole instead of a mere local deformation. Dr. Carl Barus is quoted as saying that the pier he was using "squirmed like a serpent." It is, therefore, evident that contact, without intermediate parts, with the surface to be measured is of prime importance. Four types of instrument have been suggested, three of which involve interference of light. Two use some liquid surface as the fixed level, and the other two depend on some kind of flexure-bearing. Of the flexure-bearing instruments, one, designed by Ishimoto of the Japanese Earthquake Research Institute, employs a horizontal pendulum, while the instrument developed in the Interferometric Section of the Bureau of Standards uses a vertical pendulum.

Fabry level--The liquid-surface instrument described by Professor Fabry (C.-R. Acad. sci., v. 193, p. 99, July 15, 1931) uses the interference between the top and bottom surface of a liquid, the bottom surface being slightly curved so that any tilt of the top surface will produce a movement of the system of concentric circular fringes. In this, the sensitivity is a function of the radius of curvature of the bottom of the dish holding the liquid, and may be chosen to suit the particular problem. This instrument is particularly suited for use as a sensitive level where the setting of the circular fringes may be made with reference to a circle engraved on the bottom of the dish in a manner similar to the setting of an ordinary bubble-level. Straight fringes could be obtained instead by making the bottom of the dish flat. For measuring changes in level such a system of straight fringes would probably be better adapted. In the case of straight fringes being used the method of reading could be the same as that used with the instruments with which I have been experimenting.

Free-surface liquid--The other type of liquid-surface instrument is one with which experiments are being carried on at the Bureau of Standards. A plane plate forms one end of a short cylindrical vessel which is inverted over a dish of liquid so that interference is obtained between the light reflected from the upper surface of the liquid and that from the lower surface of the plate. This plate and its supporting cylinder (which may be made of fused quartz) do not touch the dish containing the liquid but rest on the rock or other surface and tilt with it. The central part of the free surface of the liquid should remain approximately level. The reference circle with its crossed diameters is ruled on the under surface of the fused quartz plate.

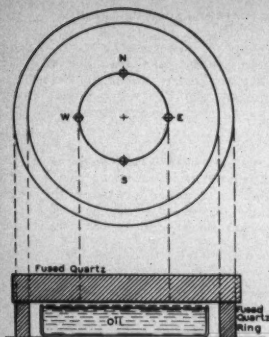


Fig. 1--Free-liquid-surface tiltmeter, showing reference-circle common to both types Bureau of Standards instruments

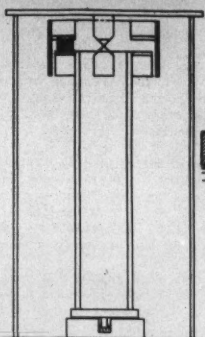


Fig. 2--Vertical-pendulum tiltmeter corresponding to Fig. 1, based on the interferometer

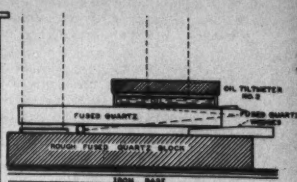


Fig. 3--Diagram set-up used to compare readings free-surface tiltmeters with true tilt



Fig. 4--Interferometric level designed by Fabry --could be used with slight modifications as a tiltmeter

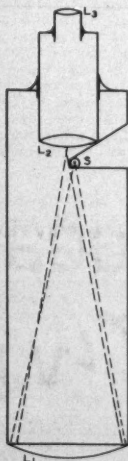


Fig. 5--Optical arrangement to illuminate and to view fringes interferometric tiltmeters

Horizontal pendulum--The horizontal-pendulum instrument as developed by Ishimoto is extremely delicate and subject to the objection that only the component of tilt in one direction is obtainable with a single instrument. The delicacy of suspension is necessitated by the fact that the tilt is measured by an optical lever and in order to perceive the effect of small tilts the angular motion must be magnified by making the horizontal pendulum very sensitive. Because of the superior sensitivity of the interferometric method the angle of tilt may be read directly and hence more rugged construction of the instrument is possible.

Vertical-pendulum instrument--The vertical-pendulum instrument developed at the Bureau of Standards has for its reference-plane the lower surface of a fused quartz plate attached to the bottom of a fused quartz cylinder, the whole forming a pendulum supported by a gimbal mounting consisting of four sets of crossed springs. The tilting plate may, in this case, be laid directly on the surface of the rock or other body to be measured. This plate is also of fused quartz and the reference-circle is inscribed on its upper face. In the center of this lower plate is a hole containing some viscous liquid and a stud cemented to the face of the upper plate dips into this cup, thus damping out vibrations.

Location of instruments--No matter how sensitive the instrument may be, its indications apply only to the immediate part of the mass to be examined covered by the instrument. It is by no means certain that the rest of the block is behaving in a like manner. The only way to find out exactly how a given large mass is behaving would be to place a number of instruments at selected points over the block. With simple instruments of the kind I have been studying, this would be quite practicable since both construction and installation is simple and comparatively inexpensive. The free-liquid-surface instruments are particularly simple in construction, and while it would not be well to depend upon them unreservedly, in combination with pendulum-instruments at control-stations a system could be worked out which would certainly give

much more complete data on the movements of whole countrysides than a few central stations, no matter how well equipped.

Thermal effects--In the experimental work so far the greatest tilts found naturally, that is, on floors, piers, etc., have been plainly caused by thermal effects. In fact, it seems probable that if a sufficiently complete analysis had been made it would be found that all the warping of basement floors, etc., would have turned out to be of thermal origin. The difference between a cloudy day and one during which the wall of the building was receiving intense isolation was perceptible in the movements of the basement floor. In locating the instruments, therefore, it is of great importance that they be placed on a part of the rock sufficiently under ground so that thermal effects will be eliminated or at least simplified to such an extent as to be easily analyzed. An incidental advantage of the interferometric instrument is the fact that it may be read from a distance and hence may be located at the bottom of a narrow shaft ten or twenty feet deep and read from the surface. Experience will undoubtedly show us how to locate our instruments so that the number needed will be a minimum. After accumulated experience it should be possible to extrapolate the results with confidence to considerable distances.

Oceanographic problems--This suggests the consideration of the possible application of the interferometric tiltmeters to oceanographic problems. In order to properly interpret data taken along coasts and on islands, it will be necessary to accumulate considerable data on the behavior of various types of land areas and also to study the effects of tidal loading on various types of known submerged strata. The tilts in marginal strata produced by the rising and falling ocean-tides will probably be considerable and it seems possible that a study of any differences between the indications of instruments placed at equal intervals along the coast might lead to information of value regarding the adjacent submerged areas.

Tidal loading--Incidentally, the study of tidal loading will, itself, be important.

Engineering structures--Another line of research not strictly geophysical, for which the tiltmeters should be useful, would be the effect on the surrounding strata of the construction of large engineering structures, such as dams, canals, buildings, tunnels, etc. A disastrous flood took place in California because of the failure of the strata adjacent to a certain dam. If information as to the behavior of these supports had been previously gathered, it might have been possible to change the design of the dam and prevent the failure which occurred.

Isostasy--The subject of isostasy is an important one among geophysicists. Tiltmeter-measurements in connection with the movement of large masses by erosion and deposition should certainly be of interest in this connection.

Volcanology--Tiltmeters placed in the area surrounding an active volcano would probably show tilts of considerable magnitude, possibly even large enough so that it would be necessary to reduce the sensitivity of the instrument. Such tilts, before an eruption, could probably be interpreted as indicating changes in pressure, or, after a disturbance, as changes in load caused by shifting of masses of lava.

Other interpretations will probably occur to those familiar with the subject.

Prognostication of earthquakes--In one respect the study of tilts differs from that of any other phenomena connected with earthquakes; it may be carried on before as well as after the shock has taken place. For this reason, it seems promising as a means of possible prognostication. Even a faint possibility of results in this direction would justify support being given this line of work. The promise of results seems much better than possible; I would almost be willing to call it probable.

Summary--Measurement of tilts is of interest and value in connection with many problems of geophysics. Interferometric instruments, because of their rugged and simple construction and their direct connection with the Earth, are conveniently applicable to this work. The comparative cheapness and ease of reading of this type of instrument makes a multiplication of observation points possible at minimum expense.

U. S. Bureau of Standards,
Washington, D. C.

SEISMOLOGY AND STRUCTURAL GEOLOGY

W. T. Thom, Jr.

It is an axiom that the world's major seismic zones coincide with the zones in which crustal deformation is now in progress, and it is therefore evident that seismology and structural geology have many interests in common. And one has only to recall the importance of the third dimension--depth--to structural geology to realize how much reason geologists have to turn to the seismologists and other geophysicists for help in solving their fundamental problems. For, granting that erosion has made available for study a vertical section of the Earth's crust amounting to perhaps five miles, it yet remains true that to date the study of earth-structures has, for the most part, been developed on the basis of surface-observation, plus speculation. This is not the whole truth, because the studies of oil company geophysicists, and of other geophysicists, are coming to be known and appreciated by students of tectonics, but even so the structural geologist still lacks a number of basic facts which he must have if he is to arrive at clear-cut and definite answers to a number of fundamental questions regarding the nature of the deformational process and regarding the character of the structural features characteristically produced by tectonic disturbances.

(1) To what extent is the concept of a rigid and brittle "crust" resting upon a relatively mobile "zone of flow" really a valid one? (2) What is the real constitution of the Earth? Does it consist of a series of concentric "shells" of different density and constitution, or do density and composition change fairly uniformly with depth? (3) If the Earth has an outer crust, does this crust maintain essentially the same strength and competence over the whole globe, or is the granitic sial really separated or separable into discontinuous blocks "floating" upon a world-wide layer of basaltic "sima"? (4) How far can mountain-building stresses be transmitted? (5) Why have continental uplift and mountain building recurred time after time throughout geologic history? (6) Are ocean-basins necessarily permanent, or may they not be produced deformationally, as is supposedly the case of the Indian Ocean? (7) How are magmas formed and why? (8) How large is a batholith and what is its shape? (9) What are the relations between tectonic disturbance and volcanic activity? (10) Why do periods of folding and thrust-faulting appear to be followed after a moderate lapse of time by secondary normal faulting and block-rotation--that is to say, by tensional rather than compressional effects?

These and a host of other questions can only be answered if carefully planned geological and geophysical studies of regions of past crustal disturbance are coupled with similar studies, carried on over an extended period, in regions of present crustal instability.

Geologists and geophysicists engaged in searching for oil are continuing to collect a wealth of information regarding the more superficial structural features characteristic of regions affected by relatively slight deformational movements, and mining geologists and engineers have also collected much data regarding the nature of past earth-movements in local areas of more marked disturbance. (Unfortunately for science, much of the geologic information yielded by petroleum and mining work--even though its release would not sacrifice company interests--has not as yet become available for research use.) But granting that this is so, it nevertheless continues to be true that attainment of a scientifically satisfactory understanding of earth-constitution and earth-mechanics cannot be had without assistance from the students of seismology. And I imagine that the converse is also true--that the seismologists cannot completely appreciate the number of seismological problems and the approach to their solution without geological advice as to the cause of velocity-variations in different azimuths, and as to the cause of other anomalies which are induced by structural inhomogeneities within the Earth.

There are three general ways whereby--in my opinion--seismology, or seismic method, can be especially helpful to structural geologists at the present time.

First, by joint geological and seismological study of an area of notable seismic activity in which observations can be made: (1) Of the influence of faulting upon earthquake genesis; (2) of the influence of faults and fracture-zones upon rate and

intensity of earth-wave propagation; (3) of the existence or persistence of earth-tremors or movements not immediately connected with earthquakes; (4) of the exact nature and amount of lateral and vertical movements contemporaneous with, antecedent to, or subsequent to earthquake-shocks; and (5) of the cumulative amount of such movements during past geologic time, as revealed by geologic and physiographic relationships existing in the region studied.

Second, in connection with an extension of the studies just described into a faulted and folded region in which natural seismic activity has largely or wholly ceased, but in which the results yielded by geological study and by modern gravitational and electrical exploratory methods can be confirmed and expanded by use of artificially produced seismic waves. This would be particularly important in disclosing the nature and condition of mountain roots; the presence or absence of deep-seated magma reservoirs; and the form and characteristics of folds and fault-blocks partly buried by basin fill.

Third, by the extension of both geologic and seismic studies to some oceanic sector which offers particularly favorable opportunities for a concerted attack upon fundamental seismological and geological problems. In deep-sea areas, the form of the sea-floor directly expresses the deformative movements which have occurred there--folds and fault-scarps being unmodified by erosion, and some idea as to the nature of the surface form produced by earth-deformation can there be obtained directly by the use of modern sounding-methods. Moreover, seismic determinations of the velocity of wave-propagation beneath the oceans can quite certainly be coupled with gravimetric measurements to determine the degree of consolidation, relative density, and probable character of the rocks composing the sea-floor which, of course, lie so deep as to be unapproachable for examination by ordinary geologic methods.

It is believed that the suggestions made above indicate that seismology can have an even greater future usefulness if it is more and more used in connection with research in structural geology, and if it is not limited to use in connection with the more immediate problems of engineering construction, water supply, or urban planning.

Furthermore, it is my belief that whether one proceeds from the standpoint of the structural geologist, the geophysicist, the engineer, the mining geologist, or the educator, there is no phase of research activity which promises results of greater practical and intellectual interest than can be obtained by a moderate and carefully planned expansion of current seismological studies. Nor, indeed, do I hesitate to say that satisfactory progress in solving the more fundamental problems of geology is dependent upon a linking up of tectonic and seismic studies along the lines suggested, and in connection with earth problems such as those which I have enumerated.

Princeton University,
Princeton, New Jersey

EARTHQUAKES IN THE NORTH ATLANTIC AS RELATED TO SUBMARINE CABLES

V. P. de Smitt

(Abstract)

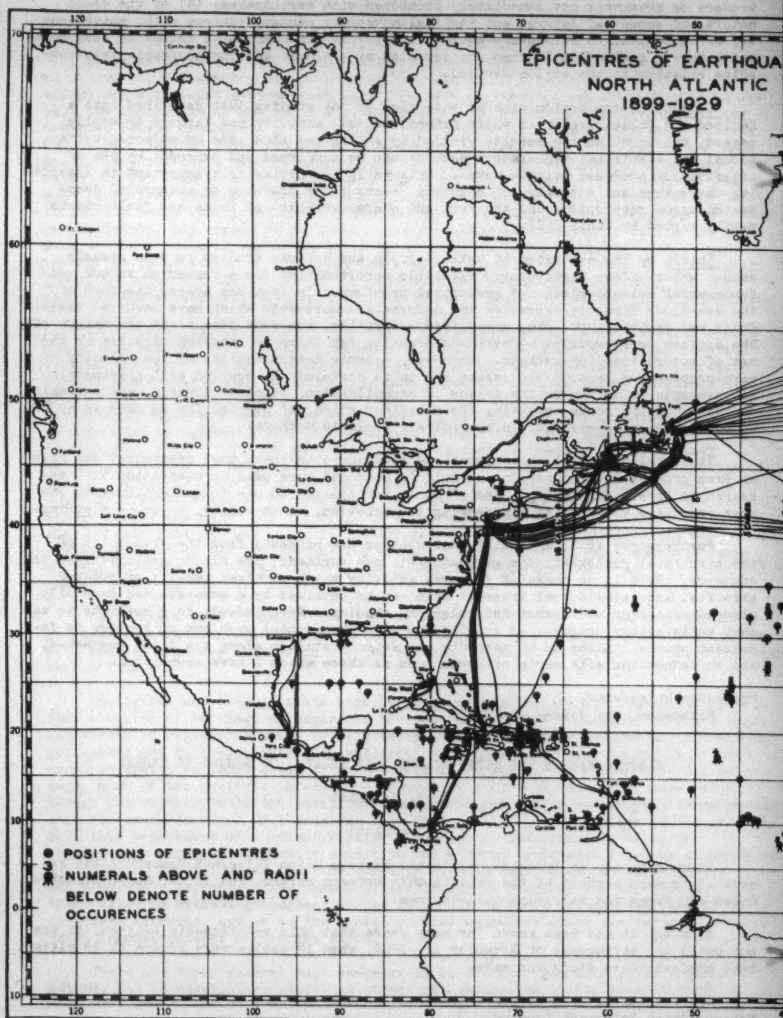
In my capacity as Hydrographer to the Western Union Telegraph Company I was requested to make a study of the relationship between earthquakes in the North Atlantic Ocean and submarine telegraph cable-breaks.

Although it had been known for many years that this relationship existed, it was not until the earthquake of November 18, 1929, when 12 cables were broken in 28 places, that any extensive study was made.

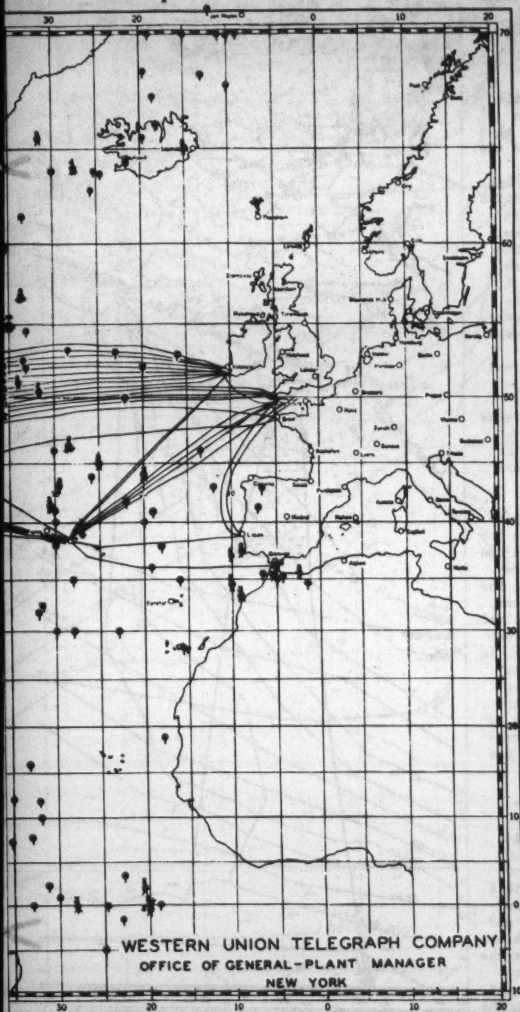
The results of this work are presented at this meeting by kind permission of the Western Union Telegraph Company.

As may be easily seen the work has two aspects, (1) the accumulation of earthquake-data and (2) the data of cable-breaks. While the first data can be reached fairly well,

Fig. 1--Epicenters of earthquakes, North Atlantic,



1899-1929



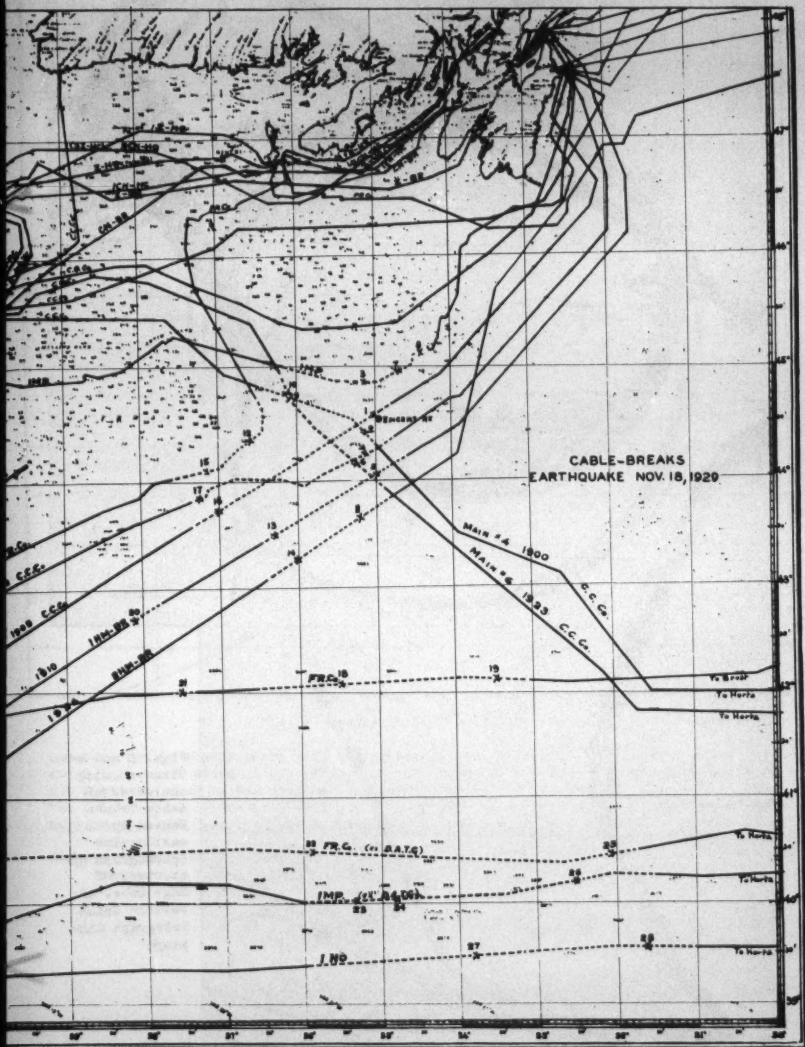
the history and the details of cable-breaks are much more complicated due to the fact that the cables belong to several telegraph companies and the records of earlier years are sometimes inaccessible.

The cooperation of the Commercial Telegraph Cable Company, the French Telegraph Cable Company, and the British Imperial and International Communications, Limited, in supplying data on cable-breaks is therefore gratefully appreciated.

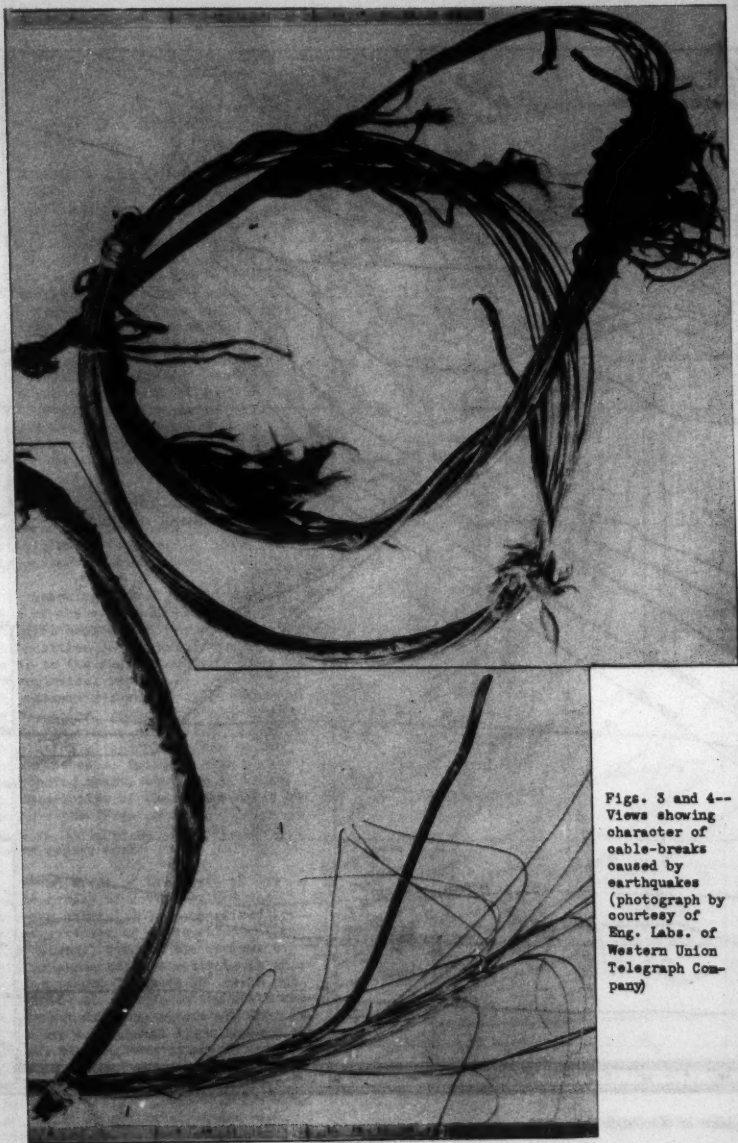
The relationship of cable-breaks to earthquakes was first shown by Prof. John Milne in 1897 in his paper "Sub-oceanic changes." He said that the most important evidence of sub-oceanic change is to be found in the fact of cable-breaks and that the establishment of seismographs on the borders of oceans would give a great practical result in determining the districts to be avoided when laying telegraph cables.

The following sources of information for the earthquake-data have been studied: (1) E. Rudolf, "Ueber Submarine Erdbeben und Eruptionen"; (2) Hollis Godfrey, "Earthquake hazard along the North Atlantic seaboard"; (3) Publications of the Dominion Observatory, Ottawa, Canada; (4) The location of epicenters 1911-15, 1917-27; (5) British Association for the Advancement of Science, "Seismological Committee's reports 1899-1930."

The more reliable earthquake-lists begin with the year 1899, when the first determination of the location of the epicenters from seismographic records was made possible.



earthquake of November 18, 1929



Figs. 3 and 4--
Views showing
character of
cable-breaks
caused by
earthquakes
(photograph by
courtesy of
Eng. Labs. of
Western Union
Telegraph Com-
pany)

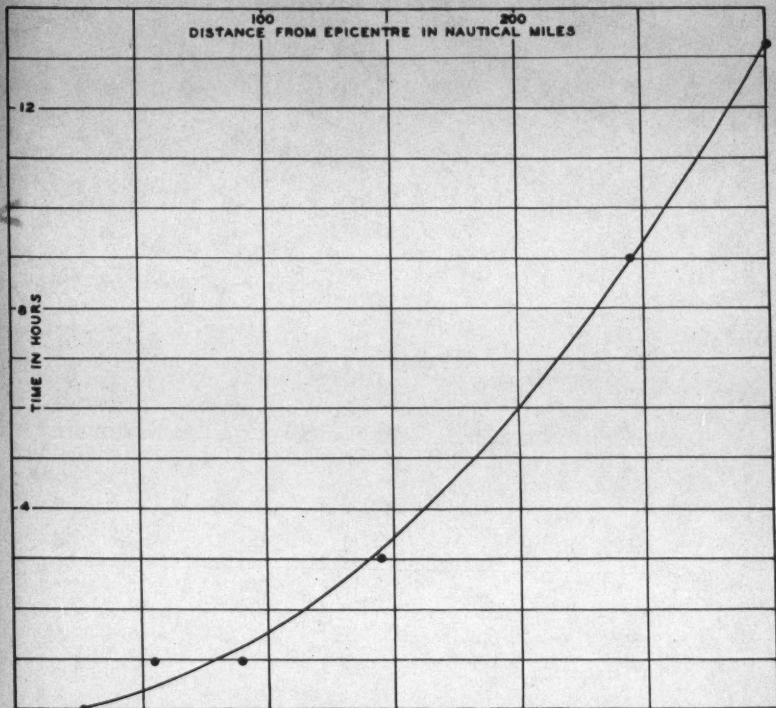


Fig. 5--Propagation of destruction

ocean-narrow in the northern part and broadening to the south, 355 nautical miles long and 210 nautical miles wide, with breaks radiating outward from the epicenter and with not a single break on the shallow continental shelf, and (4) that the ocean-floor in the neighborhood of the breaks is rather even with an average angle of slope with the horizon of $1^{\circ} 50'$ and that about one-half the breaks were on a slope of less than 1° .

Western Union Telegraph Company,
Engineering Laboratories,
New York, New York

BLANK PAGE

AMERICAN GEOPHYSICAL UNION

Thirteenth Annual Meeting

REPORTS AND PAPERS

SECTION OF METEOROLOGY

Washington, D. C.

Apr 11 28, 1932

CONTENTS

	PAGE
SECTION OF METEOROLOGY.	111
Weather Bureau program for the Second International Polar Year. W. R. Gregg .	113
The use of Polar Year data in the study of atmospheric interchange. W. J. Humphreys	116
A program for the observation of weather-changes during the total solar eclipse of August 31, 1932. S. P. Fergusson and Charles F. Brooks.	117
Determination of atmospheric turbidity. Herbert H. Kimball.	121
On winds in the upper atmosphere. E. O. Hulburt	124
Winds of the Antarctic. W. C. Haines.	124
A study of the interrelation between air-temperatures in California and ocean-temperatures in the northeast Pacific and its influence on long-range forecasting. A. F. Gorton.	128
Notes on the exchange of energy between ocean and atmosphere. W. F. McDonald. .	131
Weather-charts for the northern hemisphere. E. B. Calvert	136
Fifty years of North American rainfall. Oliver L. Fassig.	140
Atmospheric water-vapor. Frederick E. Fowle	141

WEATHER BUREAU PROGRAM FOR THE SECOND INTERNATIONAL POLAR YEAR

W. R. Gregg

At a meeting of the Polar Year Commission in Innsbruck, Austria, during September, 1931, the question was raised as to whether, in view of the world-wide economic condition, the plans for the Polar Year should be deferred until some future time when they could be carried out more completely and satisfactorily than is now possible. After considerable discussion, in the course of which it was pointed out that a great deal of preparatory work, already accomplished in outlining and organizing the program, would have to be repeated in case of postponement, it was decided to proceed with the project. The following resolution was accordingly adopted: "The Commission is of the opinion that the observations already assured during the Polar Year, 1932-1933, will be of such importance that the researches outlined should be carried on during 1932-1933." This resolution was indorsed by the International Meteorological Committee at its meeting in Locarno, Switzerland, October 1, 1932, thus assuring the prosecution of the Second International Polar Year program, though probably on a somewhat reduced scale.

In harmony with this decision the Weather Bureau is organizing its own part of the program, and in fact this organization is now very nearly complete. The program embraces two chief features: Surface observations and upper-air observations.

Surface observations--As has been stated previously (Trans. Amer. Geophys. Union, 12th annual meeting, 81 to 84, 1931), the Second Polar Year differs from the first in that it is world-wide in scope, whereas the one in 1882-83 was limited for the most part to polar and sub-polar regions. It is planned to secure as complete a network of observations as possible from Pole to Pole, including the temperate and tropical zones. For this part of the program the Weather Bureau already has a sufficiently comprehensive network of stations, in the United States proper and in Alaska, the Hawaiian Islands, and Porto Rico. The stations to be included in the program will be selected by the International Commission. At these stations observations of the principal meteorological elements including pressure, temperature, moisture, wind, sunshine, cloudiness, precipitation, etc., will be made twice, in some cases three or more times, each day and will be entered on special forms provided for that purpose. These forms will be forwarded to the International Commission, and with them will probably also be included copies of certain of the automatic records and special observations of cloud types, heights, and movements. It is expected that the Commission will have the forms and records manifolded for distribution to the different meteorological services. Provision will probably be made also for charting the data, furnished by all meteorological services, on synoptic charts for the purpose of studying in greater detail than has heretofore been possible, the atmospheric circulation between the polar regions and lower latitudes.

Aside from the purely meteorological observations certain stations will furnish data concerning radiation and auroras. Automatic records of the total solar radiation received on a horizontal surface will be continued at Washington, D. C.; Madison, Wisconsin; Lincoln, Nebraska; Chicago, Illinois; New York, New York; Twin Falls, Idaho; Pittsburgh, Pennsylvania; Gainesville and Miami, Florida; Fresno and La Jolla, California; New Orleans, Louisiana; and Fairbanks, Alaska. Observations of the aurora, probably instrumental in part, will be made in Alaska at Point Barrow, Nome, Fairbanks, and Juneau, and at selected stations in the United States, particularly those along the northern border.

Upper-air observations--For the upper-air part of the program three groups of "days in each month, two days in each group, have been designated by the Commission as International Days." The groups are classified as of the first-, second-, and third-order, to indicate their relative importance in the program. All meteorological services are urged to arrange for observations on all days in the three groups, if possible, but, if this cannot be done, then on those of the first and second groups, or, if only a limited participation in the program is possible, the most important days, those in the first group, are to be chosen. The observations are to be made at three different times in each group of two days, so that for the full program nine observations will be made at each station each month. The times are those selected by the Commission and are the same (Greenwich) for all parts of the world.

Special emphasis is placed on the desirability of securing data within the stratosphere, including temperature as well as wind. Observations for this purpose would be of particular importance in the polar regions, for which there is practically no definite information as to the height and temperature of the base of the stratosphere.

The upper-air program can be carried out quite satisfactorily, so far as the Weather Bureau is concerned, with very little extension of its already existing service. In the United States proper there are now nearly 70 stations at which pilot-balloon observations are made, weather permitting, two to four times daily throughout the year. These ascents reach varying heights, depending on visibility and other factors. Unfortunately they provide no data whatever above the base of cloud layers, but they do give a good picture of upper-wind conditions during clear weather and at all heights below cloud layers during cloudy weather. Some of them, moreover, reach well into the stratosphere and yield some information regarding air movements there.

Daily observations by means of kites, captive balloons, and airplanes will be continued at a small number of stations in the United States. These observations will provide information concerning temperature and humidity in the lower half of the troposphere.

In addition to these two lines of investigation it is planned to make sounding-balloon observations on the first- and second-order International Days at Ellendale, North Dakota; Omaha, Nebraska; and Dallas, Texas. From past experience it is expected that a large proportion of these ascents will reach well above the base of the stratosphere. Data regarding pressure, temperature, humidity, and wind will be provided. The three stations are so located that the latitudinal variation at different heights should be well brought out.

In Porto Rico there is one pilot-balloon station maintained by the Weather Bureau at San Juan. Observations will be made twice daily. The conditions for high ascents are particularly favorable here, and valuable data should be secured for study with other observations that may be made in the tropics.

The Bureau has no upper-air station of its own in the Hawaiian Islands, but there will be available the records from pilot-balloon ascents made by the Meteorological sections of the War and Navy departments.

For upper-wind observations in Alaska the Bureau is already quite well prepared through the organization, during the past two or three years, of service for flying activities. Pilot-balloon observations are made twice daily, weather permitting, at Juneau, Fairbanks, and Nome. In addition, a special station for the Polar Year is being established at Point Barrow, and here also the observations will be made twice daily, instead of being limited to International Days. It is believed that the data will be of great importance in connection with similar records at other proposed stations within the Arctic Circle.

Unfortunately it appears impracticable to secure data concerning upper-air temperatures at Point Barrow. Sounding balloons are of course out of the question here, or elsewhere in Alaska, because of the improbability of the instruments being found and returned. However, it is expected that airplane observations will be made at Fairbanks on the first- and second-order International Days. These will provide data up to five or six kilometers, and possibly higher in some cases. It is quite likely that some of them will reach the stratosphere, especially in the winter season.

There is a possibility also that, through a grant by the Rockefeller Foundation, a few radio-meteorographs may be available for use by the Weather Bureau. If so, they will probably be sent up on International Days at Fairbanks, Alaska, thus supplementing the information secured by means of airplanes.

All in all, it is believed that, in spite of the unfavorable economic situation, the Weather Bureau will be able, largely in connection with its regular program of service, to contribute very effectively to the success of the Second International Polar Year.

U. S. Weather Bureau,
Washington, D. C.

THE USE OF POLAR-YEAR DATA IN THE STUDY OF ATMOSPHERIC INTERCHANGE

W. J. Humphreys

What are we going to do with the Polar-Year data when we get them? Whatsoever they are good for, of course, but in so far as definite uses are made clear beforehand, to that extent the details of observation can be so provided for as to make the data acquired suitable for these uses. To be of greatest value the observations must be purposeful, and not mere records to be solemnly entombed with the pious prayer that some day a Gabriel may call them forth from their dusty vault. It is my purpose here and now to emphasize one of these uses. That is, the finding of where and how the breaks occur in the great polar reservoir of cold air, through which the frigid aerial floods find their way to lower latitudes, and in so doing play half the role of all the world's weather making--a half without which the other half could not exist any more than there can be a teetering board with but one end.

But to make matters clear let us begin at the beginning. In general the air is most heated within the tropics and most cooled in the regions about the poles. This at once leads to an interzonal circulation of the atmosphere. If the Earth were non-rotating and all ocean, or otherwise everywhere at the same level, and always had the same temperature-slope along all its meridians, then the interzonal circulation of the atmosphere would be essentially a continuous underflow of cold air from higher to lower latitudes, alike at all points along any parallel, and a corresponding overflow of potentially warm air (air that, however cold actually, would be warmer than the surface air if brought adiabatically to the surface pressure) from lower to higher latitudes. However, the Earth does rotate, and its surface is exceedingly diversified, especially in the northern hemisphere, by ocean and continent, valley, plateau, and mountain range, so that the actual resulting movement of the air is widely different from that which would obtain if the Earth were all sea and non-rotating.

This rotation, for instance, of the Earth, coupled with the interzonal circulation of the atmosphere which must persist, however much disturbed and tangled, tends to the formation of belts of high atmospheric pressure around the Earth at about latitudes 30° north and south. And these belts, which would not be stable if continuous, are broken each into more or less permanent segments by the alternation along its course of continent and ocean. The parts over the oceans are mainly intact except, usually, within a few hundred miles of land. In large measure warm tropical air flows to higher latitudes around the western ends of such segments, and cool polar air equator-ward around their eastern ends. This, to cite a specific case, is illustrated by the vast quantity of warm, humid air that flows onto and over the United States east of the Rocky Mountains from the southern portion of the North Atlantic and from the Gulf of Mexico. Here is a vast supply of moisture, but how can it be gotten out in the form of useful rain? Only by cooling it, and the best way to do that is the indirect one of lifting it aloft. A high mountain chain across the course of the warm winds would be exceedingly effective in this respect, producing frequent deluges from base to crest on the windward side, and aridity beyond.

Fortunately our mountains are not so located, and yet over all the region in question, the United States east of the Rocky Mountains, there usually, but not always, nor every summer, is a sufficient amount of rain for agricultural and other needs. During the warmer portion of the year this precipitation is owing partly, and in places mainly, to the heat thunderstorm. But there also are widespread rainstorms, less intense and of longer duration. These come in all seasons and, for the year as a whole, and the country as a whole, are our main source of precipitation. But how is the lifting of the warmer, humid air--the lifting which is essential to abundant precipitation--effected over these extensive storm areas? That is where the other end of the teetering board, the cool to cold air of the higher latitudes, comes in. Somewhere on its way to higher latitudes the warm air will encounter the colder circum-polar air; and, similarly, every outflow of cold air must somewhere encounter warm tropical air. Wherever the warm air is the aggressor it flows up over the colder air along their junction substantially as up a mountain ridge, and with the same results as to cooling and the production of rain or snow. There is one important difference, however, between the mountain and the cold air as inducers of rainfall. The mountain is fixed in position, thereby localizing the rain, while the cold air is now here, then there and yonder, and thus the resulting rains are widely distributed.

The warm air, however, is not everywhere the aggressor, only, as a rule, along its north to northeast front. Its western side is flanked by the cold air which, in its advance, mainly undercuts the warmer air and raises it aloft, or, in places, overflows and entraps portions of it which thereby are forced to rise locally. In either case showery precipitation is induced, often accompanied by thunder and lightning and blustery winds. This condition also moves forward long distances and hence its rains, too, cover a large area. Obviously, therefore, where and when, and only where and when, the warm and the cold exchange currents of air each, or either, finds the other athwart its course, there and then, and only there and then, occurs the precipitation of the traveling extratropical cyclone.

Some considerable interchange of warm and cold air there must be, because the air of the tropical regions is continuously heated and that of the polar and adjacent regions is continuously cooled. On the other hand, since the air involved is limited in quantity, and the amount of heating and cooling in the course of any 24 hours, say, likewise just so much, the resulting circulation also is correspondingly limited in strength and extent. Furthermore, such interchange between tropical and polar air as must occur might just as well be along any one meridian, or course, as along any other. The case is analogous to that of keeping a reservoir with a constant supply from overflowing by means of outlet pipes--outflow along any one is just as effective in keeping down the level of the water as an equal flow along any other would be. It commonly would occur, of course, that such a reservoir would be drained more frequently, and to a greater extent, along certain of its outlets than along others. Similarly, the arctic basin (all the northern frigid area) of cold air is more likely to drain, we believe, along some courses than along others. We would not, I think, expect this drainage to be frequent and strong across Siberia and the great highlands of Asia, in exchange with the warm winds of the Indian Ocean. Neither would we expect this interchange to be indifferent to the extent and location of Greenland, or the great mountain ranges of Scandinavia. On the contrary we would expect it to occur in largest amount and greatest frequency along those routes first encountered by the spreading cold air that are but little, if at all, obstructed by mountain ridges or other highland barriers. Such favored courses presumably are: The Mackenzie basin to Mississippi Valley route from the Arctic Ocean to the Gulf of Mexico; the Hudson Bay to Great Lakes course; the Arctic Ocean to Northeastern Atlantic track; and the Finland to Russia route.

Furthermore, it seems practically certain that in many cases an outpouring of the cold air along one of the more favorable routes will be so excessive as to drain the basin to such an extent that an appreciable time, days at least, will be required to refill it. Also, an outflow along any particular course so displaces the reservoir in that direction, and so chills that route, as to make the next outbreak more likely to follow in the wake of the first than it otherwise would be. In this way, perhaps, long spells of weather are produced of one kind in one part of the world and the opposite in another--warm and dry, for instance, in the United States and cool and wet in Europe.

These simple deductions appear to be so direct as to leave little room for doubt of their truth. However, deduction is not sufficient in this case, since many modifying factors were omitted from the premises. It must be followed up by abundant observations, especially of wind-direction at various heights, not only at many places within the Arctic Circle but also at a much greater number in the temperate zone, especially its poleward half. In this way we have first a rational hypothesis to guide our observations, and then observations by which we can test that hypothesis and so modify it as to bring it into closer accord with the facts.

In this way we also can determine which stations are the more important in the sense of furnishing data indicative of the coming weather of other regions, and which of comparatively so little importance as not to justify further maintenance. But will one year's observations be sufficient to this end? By no means, but they will help, and part of that help will be the guidance we shall get from them as to what observations should be continued and stressed, and at what stations.

U. S. Weather Bureau,
Washington, D. C.

A PROGRAM FOR THE OBSERVATION OF WEATHER-CHANGES DURING
THE TOTAL SOLAR ECLIPSE OF AUGUST 31, 1932

S. P. Fergusson and Charles F. Brooks

The circumstances of the total solar eclipse of August 31, 1932, are so favorable for a study of the effects of the shadow on the atmosphere that the Blue Hill Observatory has undertaken the collection and analysis of data in considerable detail at many places in and near the path of the shadow. An appropriation from the Milton Fund of Harvard University will be utilized in equipping about twelve stations within the shadow-path with recording instruments of the requisite sensitiveness and it is hoped that many other places within the belt of 90 per cent totality can be supplied with simpler apparatus for direct observations.

The more conspicuous effects of the shadow--a cooling of the air over which it passes and slight, apparently irregular changes of wind--have been observed during the past hundred years; more or less systematic observations have been made within the past sixty years with gradually improving technique, but, not until the eclipse of May 28, 1900, was it clearly demonstrated by Clayton, that, with instruments more sensitive than any employed hitherto, there could be detected certain phenomena characteristic of the general circulation of the atmosphere but free from the many complex modifying influences of local convection, radiation, diurnal periodicities, etc. These phenomena were observed during the eclipses of 1901, 1905, 1918, and 1925, but, apparently, in no instances were more than two or three stations adequately equipped. Clayton's description of the solar eclipse as a kind of laboratory experiment in which are eliminated practically all influences upon the atmosphere except that of a fall of temperature is very apt.

This fall of temperature causes a small irregular change of atmospheric pressure having three maxima and minima, a deflection of the wind toward the region of lowest temperature at all heights in the atmosphere, a decrease of the velocity of the wind at the Earth's surface, and, under favorable circumstances, a feeble cyclonic circulation of the wind about the area of lowest temperature. When conditions are favorable the larger effects could probably be computed, but at the present time the amplitude and time of occurrence of these phenomena can best be determined from observations.

The fall of temperature seldom exceeds 4° or 5° C, the change of pressure usually is not more than 0.5 or 0.6 mb (0.016 inch of mercury), and the deflection of the wind 15° or less; consequently, instruments capable of measuring very small quantities are necessary. The ordinary barographs, barometers, and anemographs are inadequate.

For recording pressure, a mercurial barograph modified from Draper's pattern, having a scale of five mm for a change of pressure of one mb, will probably be used since this instrument is of simple, inexpensive construction and can easily be assembled and transported. Errors due to capillarity, etc., will be avoided by the use of a tube at least 25 mm in diameter.

The thermograph will be of the Richard pattern but with the usual Bourdon tube replaced by a bi-metallic element to secure greater sensitiveness. The scale will be about 2 mm for 1° C.

The hygrograph also will be of the Richard pattern but with the hairs separated to obtain maximum sensitiveness. The hygrograph and thermograph will probably be combined in one case or cover with both elements recording on the same clock-drum as in the instruments used by the Hobbs Greenland expeditions.

The anemograph recording the direction and velocity of the wind will be a mechanically-recording combination of the Draper anemoscope and a Robinson anemometer of a portable type employed successfully during several earlier eclipses beginning with that of 1889. Directions can be read to 1° of azimuth and velocities to 0.1 m/s. The vane will be of the Patterson air-foil type which is about five times as powerful as the ordinary "arrow" vane and much more sensitive at the smaller angles of incidence.

All recording instruments will have the same time-scale (4 cm an hour) and function through a period of twelve hours, thereby providing for a continuous record several hours before and after the eclipse.

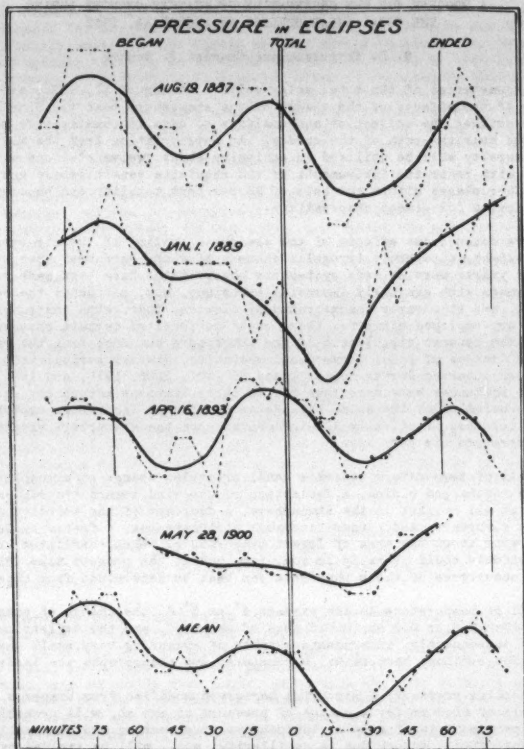


Fig. 1

For observations of clouds the simple mirror-nephoscope in use at Blue Hill Observatory will be used. The kind, amount of sky covered, direction (azimuth) of motion, relative velocity, density, and position of each level or type of cloud will be observed, and, whenever possible, additional data of heights (from dew-points, shadows, position on mountains) secured.

To determine as well as possible the local conditions the meteorological record at the various stations will begin several days before and end at least one day after the date of the eclipse.

Observations of the shadow-bands, data of which are unsatisfactory and discordant, will be made wherever possible.

Considering the fact that the shadow-path traverses, for the greater part of its length, a mountainous region where accurate data of the wind can be obtained only on the summits of hills, it is probable that a symmetrical distribution of stations can not be secured; it appears best to plan for three groups of four stations each, placed

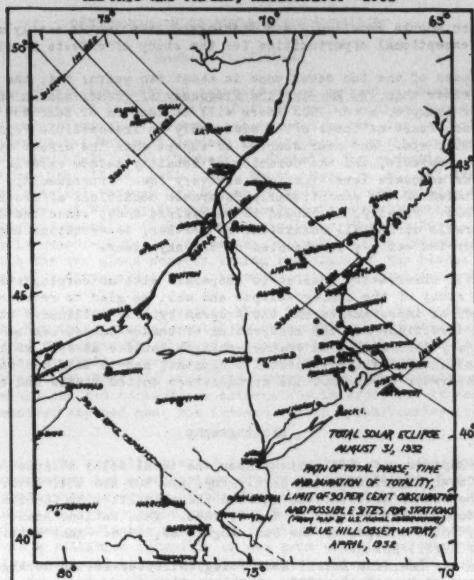


Fig. 2--Path of total solar eclipse across Quebec and New England, August 31, 1932

in zones crosswise to the shadow-path at intervals of 80 to 150 km. These twelve stations will be equipped with the special sensitive, wide-scale apparatus described. It is not intended to limit the observations and records to the immediate vicinity of the shadow-path, for important and useful data can be collected within the area or belt of 90 per cent totality. Within this belt, the borders of which extend about 650 km on each side of the path of the total phase, are, besides numerous Weather Bureau stations, some twenty observatories, chiefly astronomical, at least ten or twelve of which can probably supply observations of perhaps a higher order than could be assured from untrained volunteers who might be induced to contribute data of shadow-bands or other phenomena not requiring unusual skill.

Details of the time of occurrence, duration, degree of obscuration, and probable conditions of weather near the shadow-path are given in a "Supplement to the American Ephemeris, 1932, Total eclipse of the Sun, August 31, 1932," published by the U. S. Naval Observatory, Washington, D. C. The following data are quoted from this publication. The path of the total phase (Fig. 2), which is about 170 km (112 miles) wide, extends southeastward from near James Bay, Ontario, to York, Maine. The time (Eastern standard) and duration of totality, respectively, at a few points on this line are: Parent, Ontario, 3:18 p.m., 1 minute 43 seconds; Montreal, 3:25 p.m., 1 minute 41 seconds; Portland, Maine, 3:30 p.m., 1 minute 38 seconds. The southwestern limit of 90 per cent obscuration extends from Georgian Bay through Buffalo, New York, and Williamsport, Pennsylvania, to Wilmington, Delaware. The northeastern limit obviously is outside the boundary of the United States. The region traversed abounds in excellent, easily-accessible sites for temporary observatories and contains many first-class and other stations of the United States and Canadian Weather bureaus; consequently, since the cost of transportation of observers and equipment will be unusually small, there is available for apparatus a much larger proportion of funds for expenses than is ordinarily allowable. Within the path of totality are the highest mountains in New

England, of which Mounts Moosilauke and Washington (the latter easily accessible by railway) offer exceptional opportunities for the study of effects at different heights.

Total eclipses of the Sun occur once in about two years; but, the shadow-path is narrow--seldom wider than 190 km--and the frequency of occurrence in any region is very small. For example, after 1932 there will be none in or near New England for many years. Also, since eclipses often occur only in inaccessible regions (over oceans, the arctic, etc.) and near sunrise or sunset when the effect upon the atmosphere is inappreciable, and the duration of totality seldom exceeds three minutes, opportunities for adequate investigations are very few. Consequently, every advantage should be taken of the exceptionally favorable conditions afforded by the eclipse of August 31, 1932. Finally, it should be emphasized that, since the effect of the shadow is measurable during all conditions of weather, observations and records are important whether the eclipse is obscured or the sky clear.

The Blue Hill Observatory desires to cooperate with meteorologists and others interested in the study of the coming eclipse and will be glad to receive suggestions for additions to, or improvements on, the program briefly outlined. Other information, including directions for the observation of shadow-bands, can be supplied. Valuable supplementary information on weather-changes outside as well as inside the path of totality is obtainable without special equipment, and to this end the cooperation of interested observers throughout the northeastern United States and eastern Canada is solicited.

Bibliography

- Cleveland Abbe, Reports and observations upon the total solar eclipse, July 29, 1878. Ann. Rep. Chief Signal Officer, U. S. Army, pp. 809 and 884, 1880.
- Winslow Upton, Report of observations made on the expedition to Caroline Island to observe the total solar eclipse of May 6, 1883. Mem. Nation. Acad. Sci., v. II.
- W. H. Pickering, Total eclipse of the Sun, August 29, 1886. Ann. Astr. Obs. Harvard College, v. XVIII, No. 5.
- Winslow Upton and A. Lawrence Rotch, Meteorological observations during the total solar eclipse of August 19, 1887, at Chlamosino (near Iwanowo), Russia. Amer. Met. J., v. IV, 1888.
- Winslow Upton and A. Lawrence Rotch, Meteorological and other observations made in connection with the total solar eclipse of January 1, 1889, at Willows, California. Ann. Astr. Obs. Harvard College, v. XXIX, 1892.
- John Eliot, A discussion of the observations recorded during the solar eclipse of 22 January, 1898, at 154 meteorological stations. Indian Met. Mem., v. XI, Part II.
- H. Helm Clayton, The eclipse cyclone and the diurnal cyclones. Ann. Astr. Obs. Harvard College, v. XLIII, Part I, 1901.
- H. Helm Clayton, The eclipse cyclone, the diurnal cyclones and anticyclones of temperate latitudes. Quar. J., R. Met. Soc., October, 1901.
- Frank H. Bigelow, Eclipse meteorology and allied problems (chiefly the eclipse of 1900). Bull. I. U. S. Weather Bureau, 1902.
- H. Helm Clayton, The eclipse cyclone of 1900. Quar. J., R. Met. Soc., January, 1903.
- W. Van Bemmelen, Observations made during the Sun's total eclipse, May 18, 1901, at Karang Sago, West Coast of Sumatra. Part II, App. III, Obs. R. Mag. Met. Obs., Batavia, Java, 1903.
- H. Helm Clayton, The meteorology of total solar eclipses. Ann. Astr. Obs. Harvard College, v. LVIII, Part III, 1906.
- Various authors, Rapport de la Mission Aeronautique envoyée par le Ministre de l'Instruction Publique à l'effet d'observer en ballon l'eclipse soliel du 30 août, 1905 dans de region Constantine, Algerie. L'Aerophile, Février, 1906.
- H. H. Kimball and S. P. Fergusson, Meteorological and other observations during the total solar eclipse of June 8, 1918. Mon. Weath. Rev., January, 1919.
- Charles F. Brooks, Clouds in east Texas on June 8, 1918. Mon. Weath. Rev., March 1919.
- S. P. Fergusson, Results of observations of clouds during the solar eclipse of June 8, 1918. Mon. Weath. Rev., March, 1919.
- S. P. Fergusson, Meteorology of the total solar eclipse of 1925. Bull. Amer. Met. Soc., October, 1925.

Blue Hill Observatory,
Hyde Park, Massachusetts

DETERMINATION OF ATMOSPHERIC TURBIDITY

Herbert H. Kimball

Measurements of the intensity of screened solar radiation--Beginning with February, 1932, measurements of the intensity of direct solar radiation have been obtained through the red and yellow glass screens recommended by the Commission on Solar Radiation of the International Union of Geodesy and Geophysics at its conference at Berlin and Potsdam, February 23-26, 1931 (Herbert H. Kimball, The radiation conference at Berlin and Potsdam, Feb. 23-26, 1931. *Mon. Weath. Rev.*, v. 50, 187-188, May, 1931). The screens were obtained through Dr. Suring, Director of the Potsdam Meteorological-Magnetic Observatory. A Weather Bureau thermoelectric pyrheliometer, exposed in a Marvin pyrheliometric mounting (U.S. Dept. Agriculture, Weather Bureau, Pyrheliometers and pyrheliometric measurements. Circular 2, Solar Radiation Investigations Section, p. 6, 1931), with the two glass screens taking the place of the blades of the shutter at the outer end of a diaphragmed tube, is employed in the measurements.

The equatorial clock-driven mounting keeps the tube pointed quite accurately towards the Sun, but this is supplemented by frequent hand adjustments. The electrical mechanism designed to rotate the shutter a quarter-turn each minute is operated by hand at such time-intervals as are desired, usually about ten minutes, to successively measure the current when there is no screen between the pyrheliometer and the Sun, and when the yellow and the red screens are alternately interposed. At the same time a Marvin pyrheliometer, exposed near the thermoelectric pyrheliometer, is continuously read.

The thermoelectric pyrheliometer at present records on a Leeds and Northrup recording-potentiometer, and a comparison of the record obtained when no screen is interposed with synchronous readings of the Marvin pyrheliometer makes it possible to obtain from the millivolts of current generated in the thermopile of the pyrheliometer the gram calories per minute per square centimeter of radiation intensity. In the thermopile in use a radiation intensity of one gram calorie per minute per square centimeter generates a current having an electromotive force of about 7.2 millivolts.

Atmospheric depletion of solar radiation--The primary object of the measurements of screened solar radiation given in Table I is to determine the value of the coefficient of atmospheric turbidity, β , or the atmospheric depletion of solar radiation by scattering, aside from the scattering by the gas molecules of dry air.

According to Fowle and others, the depletion of solar radiation of a given wavelength, λ , through atmospheric scattering, may be expressed by the equation

$$I_{\lambda} = I_{0\lambda} e^{-(a_1 + a_2)m} \quad (1)$$

Here, I_{λ} = the measured intensity of solar radiation of wave-length λ ; $I_{0\lambda}$ = the intensity of radiation of the same wave-length before it entered the atmosphere; e = the base of the Napierian system of logarithms; a_1 = the coefficient of extinction of solar radiation of wave-length λ , through scattering by atmospheric molecules; a_2 = the coefficient of extinction through scattering by other constituents of the atmosphere, principally dust, and which also may be represented by β/a_{λ} (for ordinary atmospheric dust $a = 1.3$, as contrasted with 4.0 for molecular scattering and therefore, while the scattering for dust is a function of the wave-length λ , the value of the coefficient β is independent of wave-length); and m = the air mass, or the length of the path of the solar rays through the atmosphere in terms of its length when the Sun is in the zenith, or approximately the secant of the Sun's zenith-distance.

In Smithsonian Meteorological Tables, Fifth Revised Edition, 1931, Table III gives values of $(1 - e^{-a_1})$, or a_{λ} , the atmospheric transmission-coefficient for pure dry air at a pressure of 760 mm, for wave-lengths between 0.3604 μ and 2.442 μ . There are also given values of the relative intensity of solar radiation, $e_{0\lambda}$, over the same range of wave-lengths, and likewise its intensity after passing through pure dry air at 760 mm pressure. At the foot of each column will be found the relative intensity of energy in selected sections of the spectrum, and it may be determined for any section desired.

Table 1--Solar-radiation measurements, and determinations of atmospheric turbidity-factor β , Washington, D. C., February, 1932

Date	Hour-angle	Solar altit-ude, h	Air mass, m	I_a	I_w	I_r	β	Blue-ness of sky	Atm. dust-part. per cc	Notes
1932	h m	° ' "		gr.cal.	gr.cal.	gr.cal.				
Feb. 1	3 46 a	13 28	4.23	0.921	0.739	0.649	0.065		905	
	3 23 a	16 42	3.44	1.075	0.788	0.681	0.060			
	3 04 a	19 15	3.02	1.127	0.834	0.691	0.060			
	2 30 a	23 45	2.48	1.207	0.894	0.721	0.060			
	2 21 a	24 50	2.37	1.181	0.901	0.724	0.080			
	1 42 a	28 53	2.06	1.216	0.911	0.733	0.088	5		
	0 07 a	33 46	1.80	1.308	0.910	0.760	0.070			
	0 06 p	33 47	1.79	1.331	0.910	0.752	0.065			Stopped by clouds
Feb. 5	1 39 p	30 18	1.98	1.238	0.911	0.700	0.065		611	
	1 46 p	29 42	2.02	1.246	0.908	0.702	0.060	5		Clouds, a.m.
Feb. 8	2 19 p	26 53	2.21	1.222	0.895	0.729	0.070	6	1140	Clouds, a.m., now disappearing
	2 26 p	26 06	2.27	1.207	0.891	0.724	0.072			
	3 06 p	20 38	2.82	1.136	0.848	0.681	0.058			
	3 13 p	19 36	2.97	1.084	0.824	0.671	0.065			
	3 40 p	15 24	3.73	0.994	0.735	0.624	0.075			
Feb. 13	3 17 a	20 23	2.85	1.099	0.839	0.645	0.055		410	
	2 42 a	25 23	2.32	1.168	0.859	0.678	0.065			
	2 34 a	26 34	2.23	1.203	0.870	0.682	0.058			
	1 18 a	34 30	1.80	1.282	0.918	0.725	0.070			
	1 10 a	35 00	1.76	1.288	0.920	0.727	0.070			Clouds, p.m.
Feb. 16	3 30 a	19 22	3.01	0.986	0.736	0.611	0.075		1132	Much smoke over city
	2 48 a	25 24	2.32	1.115	0.837	0.672	0.070			
	2 41 a	26 18	2.24	1.143	0.840	0.685	0.082			
	2 02 a	31 08	1.94	1.167	0.850	0.700	0.110	4		
	1 56 a	31 56	1.88	1.164	0.853	0.697	0.115			Clouds, p.m.
Feb. 18	3 37 a	18 23	3.16	1.111	0.827	0.706	0.065		284	
	3 02 a	23 48	2.48	1.165	0.875	0.716	0.076			
	2 55 a	24 53	2.38	1.189	0.888	0.726	0.074			
	2 35 a	27 41	2.18	1.282	0.930	0.754	0.062			
	2 26 a	29 19	2.08	1.295	0.945	0.768	0.065			
	2 19 a	29 46	2.06	1.314	0.960	0.778	0.064	5		
	0 50 a	37 52	1.63	1.372	1.003	0.778	0.070			
	0 44 a	38 16	1.60	1.384	1.004	0.780	0.068			
	0 52 p	37 52	1.62	1.324	0.922	0.752	0.080			
	1 02 p	37 14	1.64	1.278	0.924	0.752	0.106			
	1 58 p	32 18	1.88	1.170	0.875	0.702	0.105			
	2 04 p	31 38	1.90	1.186	0.852	0.690	0.090			Stopped by clouds
Feb. 20	3 51 a	16 33	3.46	1.162	0.901	0.727	0.045		746	
	3 46 a	17 32	3.30	1.203	0.916	0.740	0.045			
	3 25 a	19 16	3.01	1.239	0.935	0.760	0.042			
	3 01 a	24 25	2.38	1.328	0.984	0.777	0.042			
	2 54 a	25 36	2.31	1.350	0.991	0.783	0.040			
	2 45 a	26 54	2.20	1.367	1.000	0.791	0.040			
	2 36 a	28 13	2.12	1.381	1.010	0.802	0.045			
	2 29 a	29 05	2.05	1.382	1.014	0.816	0.052			
	2 24 a	29 45	2.01	1.398	1.014	0.815	0.050			
	0 48 a	38 46	1.60	1.453	1.009	0.798	0.045			
	0 36 a	39 13	1.58	1.448	0.999	0.794	0.045			
Feb. 23	1 20 a	37 36	1.64	1.218	0.891	0.716	0.115		561	Clouds, a.m.
	1 14 a	38 04	1.62	1.222	0.891	0.716	0.112			
	3 06 p	24 44	2.38	1.093	0.792	0.634	0.075			
	3 11 p	23 53	2.46	1.060	0.786	0.634	0.092			
	3 31 p	20 28	2.85	0.976	0.708	0.598	0.082			Stopped by clouds

From this table the curves of Figure 1, page lxxxiv, were constructed, except that the latter do not include the absorption by the permanent gases of the atmosphere, which is given near the foot of columns 5 to 10.

It therefore becomes possible to determine from the data of Table lll the solar-radiation intensity between any desired spectrum limits after depletion by pure dry air, provided a constant value for the solar output of radiant energy is assumed. Apparently such an assumption is within the probable error of the screened measurements, since 1007 solar-constant determinations made at Montezuma, Chile, between August 1, 1925 and July 31, 1931, give a standard deviation of ± 0.00856 .

The red-glass filter obtained from the Potsdam Observatory transmits about 90 per cent of the radiation between wave-lengths 0.625 μ and 2.850 μ , or the section of the solar spectrum that includes all the important atmospheric absorption-bands except those due to ozone. If, therefore, the intensity as measured is divided by the transmission-coefficient for the filter, and subtracted from the intensity for the entire spectrum as given by a pyrheliometric reading, the remainder will give the intensity in that part of the spectrum below 0.625 μ , which is relatively free from atmospheric absorption-bands. Then the difference between the measured intensity of radiation below 0.625 μ , and the intensity determined from Table lll will give the depletion $e^{-\alpha_m}$ in this part of the spectrum by dust, including what Fowle has designated wet dust, and some absorption by ozone. This latter must be a very small amount, since Fowle has estimated the entire absorption of solar radiation of wave-lengths greater than 0.350 μ by the permanent gases of the atmosphere to be only 0.012 gram calory per minute per square centimeter (Smithsonian Meteorological Tables, fifth revised edition, p. lxxxiv and Table lll, 1931), and by ozone, between wave-lengths 0.450 μ and 0.650 μ , to be between 0.002 and 0.010 gram calory (Frederick E. Fowle, Atmospheric ozone: Its relation to some solar and terrestrial phenomena, Smithsonian Misc. Coll., v. 81, No. 11, p. 8).

The above steps may be expressed mathematically as follows:

$$Q_m - (1/\gamma)Q_r = \int_0^{0.625\mu} I_{0\lambda} \psi(m, \beta, \lambda) d\lambda \quad (2)$$

This equation may be adapted to a screen of slightly different transmission coefficients and wave-length limits as follows:

$$bQ_m - c(1/\gamma)Q_r = \int_0^{0.625\mu} I_{0\lambda} \psi(m, \beta, \lambda) d\lambda \quad (3)$$

Angstrom integrated equation (2) for an upper wave-length limit of 0.600 μ and for different values of β and m , and plotted these integrals as ordinates against m as abscissas. The integrals for different values of β fall on curves that meet at the point where the curve for $\beta = 0$ (no depletion from dust) cuts the ordinate for zero atmosphere (Geografiska Annaler, Arg. xii, Heft 2, Ooh 3, 1930, p. 142, Fig. 5).

To adapt readings obtained with the red filters furnished by Potsdam to his diagram, Angstrom found that in equation (3)

$$b = 0.95 \text{ and } c = 1.09$$

I have applied these factors to measurements obtained at Washington with the results given in Table 1.

U. S. Weather Bureau,
Washington, D. C.

ON WINDS IN THE UPPER ATMOSPHERE

E. O. Hulburt

(Abstract)

The observations of the drift of meteor-trains have been summarized by Trowbridge (Mon. Weath. Rev., v. 35, 390, 1907), and by Kahlke (Ann. Hydrogr., v. 49, 294, 1921). Data of 74 trains in the northern hemisphere were assembled which showed that in the atmospheric levels from about 30 to 80 km there prevails an easterly wind in the late afternoon, and that at night in the levels from about 80 to 110 km westerly winds predominate in November and August; during other months the winds are either variable or the data are too fragmentary to permit trustworthy conclusions. The observations afford on the whole only a glimpse of air circulation in the upper atmosphere. One would like to know more about it and further observations of meteor-trains would be of great interest.

If, as it is believed, the atmosphere in levels above 50 km is hotter during the day than at night there will be winds blowing from the day to the night areas, hence a northward flow of the upper air in the daylight northern hemisphere. But, if nothing interferes, north-moving atmospheric currents swing to the east because of the Earth's rotation and become a west wind. In the southern hemisphere the flow is southward swinging to the east to become a west wind. At the same time if there are prevailing westerly winds in certain portions of the high atmosphere there would probably be easterly winds at lower levels, for the air must flow back somewhere. These rather sketchy theoretical inferences agree with the meteor-train observations. Further, the ultraviolet-light theory of magnetic storms and aurorae (Phys. Rev., v. 34, 344, 1929) suggests that during a magnetic disturbance the winds and turbulence of the high atmosphere are much greater than during a time of magnetic calm. This would perhaps occur in levels above 80 km but it might be lower. Meteor-train observations during magnetic storms would be of interest. [The complete paper is to be published in Publications of the Astronomical Society of the Pacific.]

Naval Research Laboratory,
Bellevue, Anacostia, D. C.

WINDS OF THE ANTARCTIC

W. C. Haines

Most people believe the Antarctic Continent is a region of very strong winds. This belief is due largely to the fact that most of the observations from Antarctica are from the coast regions where down-slope, or drainage, winds are prevalent. Antarctica with an area considerably greater than that of the United States, much of which is an ice-covered plateau of roughly 7,000 to 9,000 feet in elevation, is perfectly adapted to drainage winds. These winds become very intense on declivitous coasts, especially when they are augmented by a low-pressure area in the proper position over the ocean. This type of wind was experienced by Sir Douglas Mawson, who spent the winter of 1912-13 at Adelie Land on the edge of the Continent. He reported an average wind-velocity for an entire year, from the interior toward the sea, of more than 50 miles an hour. The maximum velocity was endured in July 1913, when an average of 107 miles an hour was maintained for eight hours, during which period gusts reached nearly 200 miles an hour. Similar winds of varying intensity and irregular duration have been reported at many stations along the Antarctic border. Captain Scott, who based at McMurdo Sound on the southwestern border of the Ross Sea at the foot of the Prince Albert Mountains, reported an average yearly velocity of 21 miles an hour, more than double that recorded at Little America 400 miles to the eastward.

Little America is located on the shore of the Bay of Whales, an arm of the Ross Sea, in latitude 78° 34' south and longitude 165° 48' west only a few miles from Framheim where Amundsen based. The Barrier edge at this point runs in an east-west direction, turning northeasterly, east of the station. Its height is approximately 150 feet. The Barrier extends as an almost level plane southward and westward for approximately 400 miles before mountain ranges are encountered to interfere with wind

movement. There are some low mountain peaks and ranges approximately 150 miles to the eastward, but their effect on winds would be negligible.

It is thought that the wind-records at Little America and Framheim are much more representative of Antarctic conditions than the records of stations along the mountainous coasts that are under the influence of drainage winds.

At Little America a record of the surface winds was kept for approximately 14 months. The anemometer and wind-vane were exposed about 20 feet above the surface of the Barrier. There were no obstructions to interfere with wind-movements.

The studies of the wind aloft are based on 415 pilot-balloon observations taken between January 15, 1929 and February 5, 1930. In general they were made twice daily during the daylight portion of the year and once daily during the dark portion, weather permitting. With but very few exceptions during flight-operations, observations were not made closer than approximately 12 hours apart.

The most frequent direction of surface winds observed was from the east and southwest. Thirty-two per cent of the winds blew from the east and east-southeast and 29 per cent from the southwest and south-southwest. The easterly winds were more frequent during the summer months, and the southwesterly during the winter months. Practically no winds blew from the northwesterly quadrant.

The velocity averaged 9.4 miles an hour for the year. The windiest month was March, which averaged 13.6 miles an hour, and the calmest was September, with an average of 8.1 miles an hour. These velocities may appear low to be recorded in the Antarctic. However, this does not mean that high winds did not occur. Occasionally velocities of 40, 50, and sometimes 60 miles an hour were recorded producing severe blizzards. The extreme velocity was 75 miles an hour on July 30. Winds of blizzard proportions occurred 37 times during the year. Calms were of frequent occurrence.

In general, south and southwesterly winds were accompanied by the coldest weather, and easterly and northerly the warmest. Blizzards were nearly always accompanied by easterly winds.

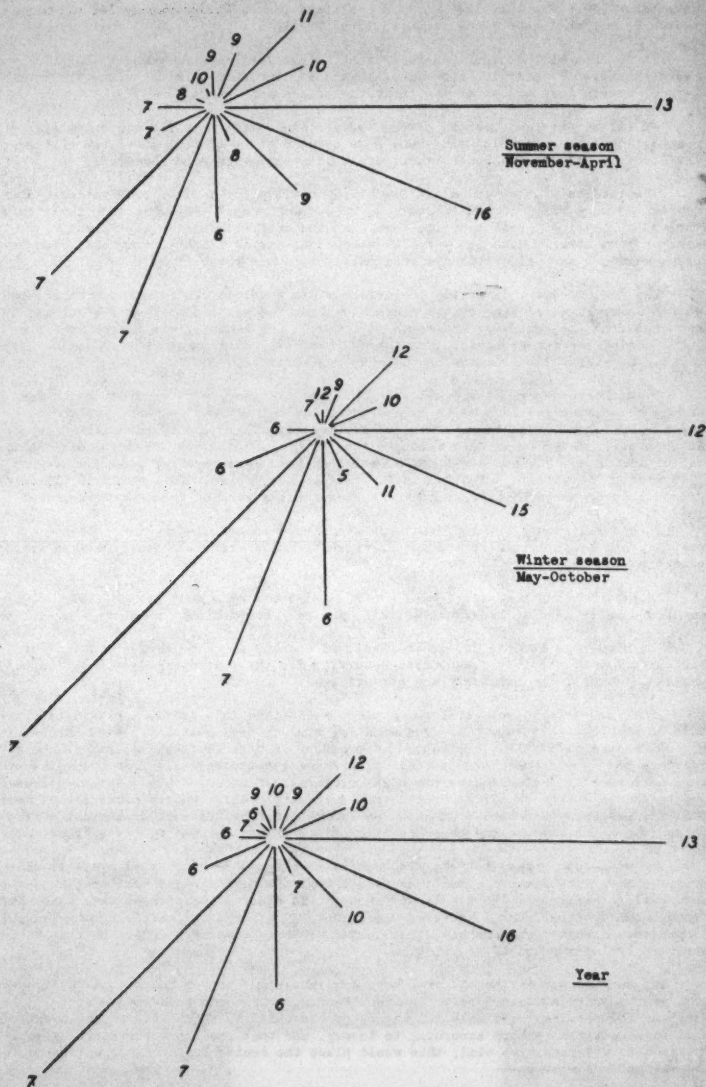
In studying the records of wind aloft, wind-roses were made for the 250-, 3,000-, and 5,000-meter levels, based on 413, 255, and 143 observations, respectively.

The wind-rose for the 250-meter level, of course, is quite similar to that of the surface, the greatest frequencies occurring for the easterly and southerly winds, and the least for the northerly and westerly.

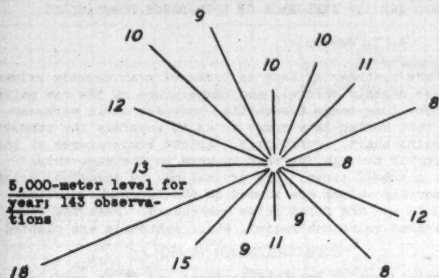
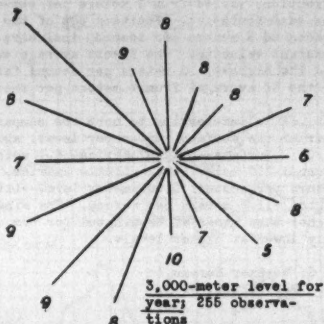
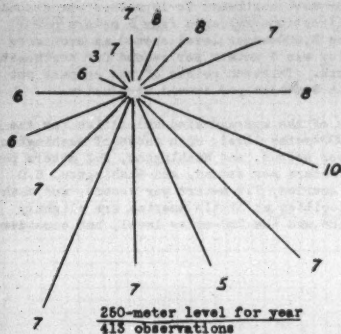
The 3,000-meter level is of particular interest as this is the approximate altitude of the Polar Plateau. The predominating wind-direction at this level should give a good indication of the distribution of pressure in high southern latitudes. This question has caused considerable discussion among meteorologists. Some think the pressure continues to decrease from the high-pressure belt at 30° south latitude poleward due to the intensity of the polar cyclone in the upper air. Others advance the theory that the pressure increases from about 68° south latitude poleward on account of the intensity of the anticyclone over the Antarctic Continent caused by the extreme cold.

The wind-rose shows that the frequencies at the 3,000-meter level are well distributed among the various directions, except that the southern and northeastern sectors show a slight weakness. Forty-six per cent of the winds at this level have a northerly component and 54 per cent a southerly component, 40 per cent an easterly component, and 60 per cent a westerly component. The larger westerly component indicates that the pressure is lower south of the station.

The same result may be obtained more accurately by finding the resultant direction and velocity at this level. The resultant direction was found to be south 77° west and the resultant velocity 1.3 meters per second. Assuming that the gradient wind parallels the isobars according to theory, and that the 255 observations give a fairly accurate resultant wind, this would place the center of the low pressure south 13° east of the station.



Surface winds, Little America (frequency represented by length of line, figures being the average velocity in miles per hour)



Winds aloft, Little America
(frequency represented by length of line, figures being the average velocity in miles per hour)

If we consider separately, the summer half-year, November to April, inclusive, based on 149 observations, and the winter half-year, May to October, inclusive, based on 106 observations, the low-pressure area is shown to be south of the station in each case.

The most striking feature of the 5,000-meter level is the predominance of west-southwest winds. This direction has a frequency of 13 per cent while the adjacent directions have only 6 per cent each. The resultant direction at this level, based on 143 observations, is north 78° west, and the resultant velocity is 2.9 meters per second. This shows the low-pressure center to be south 12° west of the station. The resultant velocity indicates a steeper pressure gradient at this level than at the 3,000-meter level, which should be expected.

These results would seem to indicate that the Antarctic anticyclone is comparatively shallow and does not influence conditions much above the level of the Polar Plateau. At this level the ordinary circulation of the atmosphere has reestablished itself and westerly winds prevail. The pressure also tends to show the non-existence of an intense anticyclone. At Little America, the pressure averaged from one-quarter inch to one-half inch lower during the colder months of the year than during the warmer. There was a difference of nearly three-quarters of an inch between the lowest average monthly pressure for the year, 28.85 inches, in October, and the highest, 29.57 inches, in December. All stations in high southern latitudes show a similar fall in pressure from summer to winter months.

In closing I desire to call your attention to the comparatively low and constant wind-velocity aloft. At the 250-meter level, the average velocity for the different

directions varied from 3 meters per second for west-northwest to 10 meters per second for east-southeast. Fourteen out of the 16 directions averaged from 5 meters per second to 8 meters per second, inclusive. The 3,000-meter level showed an even more constant velocity. The lowest average velocity was 5 meters per second for southeast, and the highest, 10 meters per second for south. Thirteen points of the compass out of the 16 averaged from 7 meters per second to 9 meters per second, inclusive.

It is interesting to note the comparison of the average wind-velocities for the year at the surface, 250-meter level, and 3,000-meter level, with those of Washington, D. C.: Surface--Little America, 4.4 meters per second, and Washington, 3.2 meters per second; 250-meter level--Little America, 6.9 meters per second, and Washington, 6.0 meters per second; 3,000-meter level--Little America, 7.9 meters per second, and Washington, 11.9 meters per second. The wind-velocities at Little America are slightly higher than those at Washington for the surface and the 250-meter level, but considerably lower at higher levels.

U. S. Weather Bureau,
Washington, D. C.

A STUDY OF THE INTERRELATION BETWEEN AIR-TEMPERATURES IN CALIFORNIA AND OCEAN-TEMPERATURES IN THE NORTHEAST PACIFIC AND ITS INFLUENCE ON LONG-RANGE FORECASTING

A. F. Gorton

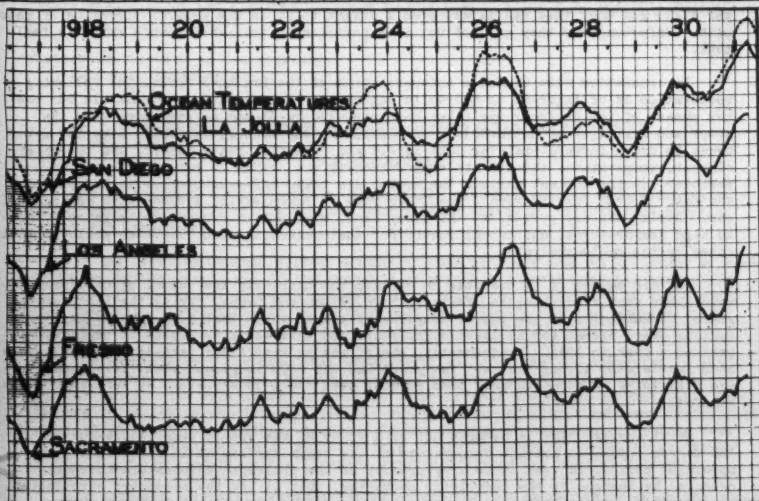
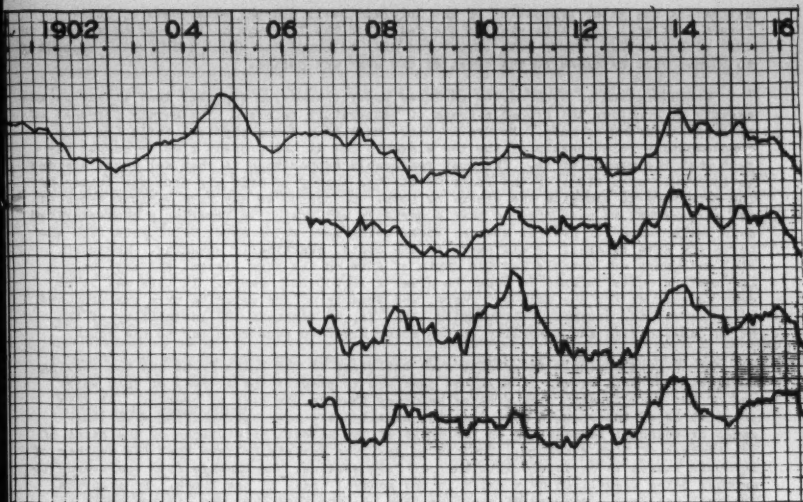
Since meteorological records are customarily kept in terms of mean monthly values, it is perhaps most convenient to use monthly rainfall and temperature as the raw materials for a statistical analysis. For long-range forecasting purposes it is moreover convenient to subject the figures to a moving-12 average so as to suppress the summer-to-winter variation. The accompanying chart, accordingly, depicts temperatures at the several stations plotted as a moving-12 average, or what amounts to the same thing since all the values are relative, a sum-12 curve. The process may be described briefly as follows: The first twelve-monthly values are summed on the Burroughs machine, then the thirteenth value is added in and the first value subtracted. Next the fourteenth value is added in and the second value subtracted, etc.; subtotals are plotted at each step.

The process is the most elemental sort of smoothing process and it is readily seen that the annual variation is largely eliminated. There remains evidence of a cycle around six years, a long or secular cycle which is doubtless the Bruckner cycle, and most interesting of all, decided upward and downward trends, here and there persisting for as much as twelve or sixteen months.

Maxima of temperature occurred in 1918, 1924, 1926, and 1931, whence it is inferred that the six-year cycle is operative with one of its crests obscured by the double peak in 1924 and 1926. This periodicity had already been observed in the McEwen index used for seasonal rainfall forecasts, the crests in this case having been noticed in 1917-18, 1923, and 1929-31. Here the spacing is of the proper order to give the six-year cycle.

Shuman (Notes on lake-levels, by J. W. Shuman, Mon. Weath. Rev., March 1931) has pointed out the apparent tendency of rainfall and temperature to move in a complementary fashion--an idea which was really first put forward by Bruckner (Klimaschwankungen seit 1700, by E. Bruckner, 1890). That is to say, Shuman believes that in the course of the Bruckner cycle (22 to 33 years in length) a warm-dry phase is succeeded by a cold-wet phase, the two being roughly of equal length. It is interesting to observe that the last fifteen years which have been so dry in California have also been quite warm and these years probably belong to the warm-dry phase, from which it follows that the next decade or so will probably be on the whole cooler and wetter.

It may be remarked that the warm-dry and cold-wet combination probably does not apply to certain parts of the country such as the lower Mississippi Valley but it undoubtedly characterizes the climate of California and probably the South Atlantic States. It is indeed a relationship which promises to be of the utmost value in



Ocean-temperatures at La Jolla and air-temperatures at four stations in California plotted as a moving-12 average--actually sum-12 curve--of the mean monthly values, plotted in the center of the 12-month period (note the parallelism between successive curves; the base-line for San Diego is 61° F and the 1931 peak-value represents 65° F as a smoothed monthly figure)

estimating the water production of the Colorado Basin and the watersheds of California. It will have a bearing on the design of the Los Angeles Aqueduct as well as on that of Hoover Dam, since both structures will be completed about 1939, which according to Shuman will be close to the crest of the next wet period.

Consideration of such curves as those under discussion suggests that it may be necessary to consider the probable trend of temperature before a trustworthy forecast of precipitation can be made. Naturally there must be a sound physical basis for such a complementary relationship of the two elements but at the present time we cannot say just what the mechanism is. The most reasonable supposition is that wet years are due to southward excursions of the Polar Front, the supply of cold air from the latter being necessary to energize the storms or Lows. Of course we may have various types of wet seasons but we have noticed that a markedly wet season is invariably characterized by a large number of general storms, these being Lows which enter California from the north and give rainfall to all parts of the State, practically speaking. Moreover, real wet years are notable for the depth of snow on the high Sierras and obviously a low must be quite intense in order to climb a 16,000-foot range. In this way it is easy to account for the cold-wet years, and seasons of the opposite type are produced by a lack of the secondary circulation, that is, by weakness and instability of the North Pacific High and inability of the Polar Front to penetrate far to the south.

If it were possible to predict such outbreaks of the Polar Front and the ensuing succession of cold waves, it might be possible to predict the arrival of cold waves and of wet seasons with much greater accuracy than is the case at present. At this point it is of interest to note that the Russians are now experimenting with long-range or seasonal forecasting on the basis of the alleged persistence of the paths of the centers of high pressure. That is to say, the Soviets believe that the weather of European Russia is divisible into four or five seasons, the passage from one season to another being signalled by a shift in the general track of the Highs. By accurate observations from a network of stations they believe that they can fix the paths of the Highs and that they can detect even a slight shift in the general direction of this path. Unfortunately they are not yet in a position to tell when such a shift is imminent.

In connection with Shuman's interpretation of the Brückner cycle, the following speculation is of interest to hydraulic engineers. The mechanism responsible for the two phases of the Brückner cycle has been pictured by Shuman as operating like the motor and brakes of an automobile. In short, the one factor, rainfall, like the motor tends to drive forward--raising lake-levels and producing heavy runoff, and the other element, temperature, through its evaporation-effect, tends to retard such action. Moreover, during the wet periods the brakes are taken off--evaporation is reduced--and the motor drives forward with a resulting rise in lake-levels, ground-water and runoff, etc. During the dry period, on the other hand, evaporation-losses are heightened, due to high temperatures, and actual runoff for that reason is even less than would be indicated by the cycle-analysis.

In this manner it is possible to explain the extremely low runoff of California watersheds such as Sacramento, Feather, Kern, Kings and Owens, during the last several years. Examination of the sum-12 temperature-curves shows that temperatures have been running above normal for at least eight years and this terrific excess of temperature reached a peak in 1931. Consequently, the effect on runoff and lake-levels should have been accelerated during the last few years and the drop in ground-water level and storage reservoirs is known to have been greater than could be explained by deficiencies in rainfall.

Still another fact is brought out by a study of the sum-12 temperature-curves. The McEwen index, or average temperature of the ocean-surface at La Jolla during the upwelling period, is seen to be a by-product of the prolonged temperature-movements produced by changes in the underlying mechanism, that is, in the secondary circulation. The upwelling itself, which in practice is measured by the reduction of the surface-temperature of the inshore water below the established normal during the summer period, is probably controlled entirely by the intensity of the North Pacific High and the behavior of the Polar Front. Variations in the McEwen index therefore are of less significance than the major movements in temperature itself. To illustrate, the cold water observed during the summers of 1916, 1924, and 1928 was a by-product of the downward

trends begun in the early portion of these three years. Similarly the high values of the McEwen index in 1917, 1923, and 1929 were produced by rising trends of the sum-12 curve which in each case persisted actually for almost a year. Such trends accompanied corresponding changes in the character of the North Pacific High and in the Polar Front. For instance, during the last three years we have had a rising tide of temperature, increasing drought, and general instability of the North Pacific High coupled with a retreat of the Polar Front. During this period general storms have been few and weak.

Taking up now the problem of seasonal temperature prediction, it is apparent that the discovery of factors, changes of which precede corresponding changes in the temperature trend, would lead to a system by which we might forecast both temperature and the demand for gas for heating purposes (A. F. Gorton, Bull. Amer. Met. Soc., October 1931). Of course, it would be desirable to have a time-lag of several months between the index and the temperature to make the forecasts of practical value. It is highly probable that such an index will be discovered shortly, judging from the success of similar temperature-correlation, notably the one dealing with winter temperatures in Central Canada (Fritz Groismayr, Relations between summers in India and winters in Canada, Mon. Weath. Rev., Nov. 1929, p. 453). Or by further development of the so-called cycle-analysis we may arrive at a similar and almost as satisfactory a result. At the present time we feel more confidence in the cycle-analysis of precipitation and runoff than we do in a similar analysis of temperature, but that is only natural considering that practically all investigators have centered their attention on precipitation rather than temperature.

In conclusion it would appear that the analysis of temperatures is of equal importance with that of precipitation and that proper consideration of the temperature-cycle with the precipitation-cycle will very materially improve present methods of forecasting the water production of the wet season in California and may lead to reliable forecasts of the trend of seasonal temperature and the corresponding demand for gas for heating purposes.

Scripps Institution of Oceanography,
La Jolla, California

NOTES ON THE EXCHANGE OF ENERGY BETWEEN OCEAN AND ATMOSPHERE

W. F. McDonald

The proceedings of the American Geophysical Union will reveal upon examination a rather large proportion of discussions upon various phases of the relation between oceans and atmosphere.

In the last two decades a great amount of work has been done in the study of heat transport in the ocean, and of its probable or possible effects upon the atmosphere. All such efforts appear to be an outgrowth of a widespread acceptance of the thought that temperature-variations in the oceans must be a primary cause of changes in our continental weather.

Any emphasis upon the idea that oceanographical controls are operative in world-weather events will be found, however, to have received great exaggeration in the popular fancy. The well-known influence of sea-surfaces and ocean-currents upon continental climates is uncritically assumed to involve an equally simple and demonstrable relation to short-term weather changes. In the absence of adequate scientific data upon the probable mechanism of such controls in weather changes, speculative thought finds free reign, and plausible theories acquire a widespread popular following.

No adequate scientific explanation is offered of the mechanism by which the ocean-surface temperatures can operate in influencing succeeding weather conditions over definite localities. We find, instead of a clear and ordered exposition, much uncertainty as to hypotheses, great obscurity in correlation of observational detail and little or no demonstrated relation of value for predicting the abnormalities of weather events. Considering the complexity of the problem involved, and the gaps which exist in our actual knowledge as distinct from our notions of the heat balance in the

Earth's atmosphere, it is decidedly premature at this time to emphasize the predictive possibilities of ocean-temperature variations in weather forecasting. Our knowledge of the history of temperature-variation in the sea-surface is so inadequate as to constitute a problem of tremendous proportions in that direction, the solution of which, in some degree at least, must precede any advance in this enticing field of speculation about resultant atmospheric or weather effects.

Marine weather-records in the archives of the world's great meteorological institutions and services appear to have been summarized almost exclusively into long-term averages, or in the form of what properly can be called only the elements of the climatology of the sea. The realization should be generally fostered that such averages, necessary as they are for base and background, have the effect, if taken along, of concealing as much as or more than they reveal. A definite program to secure the time-history as well as the arithmetical mean of the changes observed in process in and over the sea is urgently in order, and a beginning towards that desirable end is being made in the Weather Bureau.

To plan such a program aright requires, however, some effort first of all to grasp such broad principles of the mechanism of energy-relations in sea and air as seem, from the physical conditions and the results of observational investigation, to be the probable foundation upon which the work of erecting a finished structure of details will proceed.

That foundation must embody two very broad principles, namely, (a) that the oceans are characteristically accumulators of solar energy wherever that energy falls upon the sea-surface, and (b) that such accumulations are much more conservative than are the energy-stores in the atmosphere.

From these principles, which I believe will require neither argument nor detailed exposition, the well-recognized and oft-stated climatological influence of the ocean upon the land arises. But any attempt to set the details of atmospheric-oceanic interactions into simple relations upon the foundation of basic principles stated above, meets complications, reactions, reversals, and regenerations that arise in confusion--no static arrangement of parts here, but instead the most complex involutions of dynamic process. Nevertheless, a few simplifications of the apparent disorder can be conceived.

It is clear that these fluid media, the air and the oceans, jointly constitute a great heat-engine by which solar energy tends to be distributed from areas of excess to areas of deficiency on the Earth's surface. The tropics are analogous to the boiler, and the poles represent two widely separated condensers for the heat-engine. But, because of the time-rate at which work processes must proceed (not being instantaneous) and because of the continuous and remarkably steady supply of surplus heat in the tropics, the total equalization of heat-energy is never realized, even on a small scale, and there remains at all times between equator and poles a major temperature-difference.

The temperature-difference between equatorial and polar regions is very much less in the oceans, however, than in the atmosphere, being of the order of 30°C in the former and 50°C in the latter along the common surface of discontinuity. Air- and water-temperatures are approximately equal over the tropical oceans. Hence the atmosphere is, in the average, cooler than the oceans and in a state to demand heat from the ocean-surfaces. Fortunately for us, the oceans have a very large heat-capacity, and we may therefore look upon the processes of accumulation and expenditure of solar radiation as involving the following major phases: (1) Primary accumulation of heat in the upper strata of the oceans, where mobility permits extensive transport poleward within the ocean itself; (2) the transfer of a large amount of heat-energy from the ocean to the overlying atmosphere; (3) the more widespread dissemination of energy through circulation of the atmosphere onto continents and into polar regions; and (4) the final loss of the energy from the atmosphere in those localities where outgoing radiation exceeds all sources of heat-acquisition.

The point must be strongly emphasized, however, that these steps do not constitute a continuous, unidirectional process in any locality although in general the world balance between solar energy received and heat lost by final radiation to space

is maintained with remarkable uniformity by an average process which can be analysed into the major phases enumerated. The routes by which solar energy works out through oceanic and atmospheric changes are enormously complex. Phases can be found where atmospheric energy is, so to speak, in excess and therefore does work upon the sea; in other cases, and more generally, the sea furnishes power for atmospheric action. At every transfer of energy from one medium to the other or from potential to kinetic form there is a permanent loss to one medium, but some diminishing fraction may continue to pass through an indeterminate number of cycles before being finally dissipated. Little is known about the average time-scale upon which the process of heat-accumulation, transfer, and loss proceeds, but there is room for belief that some phases of accumulation and discharge require a time basis of great extent, possibly approaching the geologic scale, especially with respect to polar ice.

In view of the situation noted above, consisting of an atmospheric envelope which has a lower average temperature than the average of the free ocean-surface, heat necessarily flows over the temperature-gradient from sea to atmosphere. The nature of the fluid media involved contributes strongly to such a process of direct heat-transfer. Warming of the atmosphere at the bottom, and cooling of the ocean at the top surface so disturbs the temperature lapse-rates in each case as to be conducive to convective overturning. Insofar as convection is actually induced, the result is to bring cooler air from aloft down to the ocean-surface, and warmer water up from below, and thus to maintain the temperature differential as an effective gradient from ocean into the atmosphere.

It may be said here that a remarkable lot of evidence supports the view that there is a decided tendency for surface-air to reach and maintain a temperature slightly below that of the water surface even when the air is originally warmer than the water. The principal exceptions to this state appear to arise either along continental borders where warmer air remains so for the brief time which must elapse before the cooling processes have stabilized the temperature-relations of water and overlying atmosphere, or where there is a vigorous poleward movement of warm, practically saturated air of oceanic origin, in which case the cooling process in the air runs behind the rate at which the temperature of the underlying water-surface decreases in the direction of flow.

The injected moisture charge appears to have some part in the mechanism of the general case, in which the surface-air is somewhat cooler than the surface water, but what, exactly, goes on in this situation which affects extensive ocean-areas is quite obscure and is under investigation.

There is no room for doubt that evaporation carries tremendous quantities of heat-energy out of the oceans into the atmosphere, because the molecular energy required for vaporisation of sea-water comes from the heat-store in the ocean and not from the air into which the vapor with its latent heat passes. Any small amount of atmospheric heat contributing to the process does so after suffering conduction from warmer overlying air to cooler water, except when, in the case of stormy conditions, water as spray is carried into the air and there evaporated.

The sensible temperature of the ocean-surface must be lowered by the loss of energy accompanying evaporation. Since evaporation does not affect the temperature of the overlying air, under the quiescent conditions most generally prevalent, and the loss of atmospheric heat by conduction from warmer air to cooler ocean is a relatively insignificant process, there is in general a flow of energy out of the water into the atmosphere so long as the space adjacent to the ocean-surface is unsaturated and is therefore able to accept an increase in evaporated moisture.

The major portion of the thermal energy involved is lost forever to the sea when the water vapor leaves the ocean-surface, because condensation and release of latent heat commonly occur in the depths of the atmosphere, often over continental surfaces, so that much heat has to be lost by radiation before the air which received additional energy at the point of condensation can return to the ocean-surface.

The direct contribution of heat which can be made by a flow of warmer air to a cooler sea must in general be relatively small. By any direct heat-transfer from air to ocean the immediate tendency in both air and water is to institute states tending

strongly to retard the transfer of heat-energy out of the atmosphere into the water. The water will be warmed in its uppermost layer while at the same time the air-mass must be cooled at the bottom. The tendency is therefore towards stable stratification in both media, confining direct heat-exchange to relatively small masses which must soon reach a state of approximate temperature-balance unless forced turbulence calls into play strata which, if undisturbed, could not get into contact.

The high limit of moisture capacity per unit volume, conditioned by the high temperature of unusually hot air flowing over cooler water does, however, present a still different problem, especially when the humidity is low. There seems to be room for the view that the heat value of the moisture charge which must enter the air from the ocean in this case will in fact greatly overbalance in value the tendency for heat to move directly from air to water, and, while some equalization of temperatures undoubtedly proceeds from the lower atmosphere cooling, the sea-surface probably is not measurably warmed, but continues to deliver latent heat to the atmosphere in the form of a rapidly increasing charge of water vapor.

The high original temperature of the air-mass is thus a factor favoring a further gain of energy by the atmosphere rather than a loss of atmospheric energy by temperature conduction to the sea-surface.

The heat and moisture in the air have another very important influence, however, upon the accumulation of heat in the oceans. The rate of loss of long-wave-length radiation from the warmed surface acquired by the ocean under direct insolation is retarded by the blanketing effect of the air charged with heat and moisture. In thus minimizing the rate of loss, the final temperature of the seas under balanced radiation involving water-surface, atmosphere, and space is very much higher than could be the case were the atmosphere absent.

A special study of a case involving this relation between air- and sea-temperatures is being made in the Marine Division of the Weather Bureau for the coastal waters between the Gulf Stream and the North Atlantic States, with the hope of evaluating some facts regarding the continental influence upon water-temperatures. A brief statement of some preliminary results may be of interest here.

The winter of 1917-18 was one of the coldest of record in the northeastern United States, while the past winter (1931-32) has been perhaps the warmest of record. There was a difference between these two winters of more than 20° F in the January air-temperature at Washington, New York, and Boston.

In the sea surface-temperatures near the coast, a similar difference of the order of one-half that found in the air is revealed in the compiled data. By virtue of this difference the ocean-surface has recently enjoyed, over a large expanse near our northeastern coast, a midwinter temperature about 10° higher than that experienced in the same ocean area in the month of January 1918. There would seem to be little argument against the belief, which I do not hesitate to express, that the warmer atmospheric drift from continent to ocean in the winter just past protected the stored heat of the ocean surface by lessening atmospheric demands, and therefore contributed materially to preserving a higher winter temperature in the water-surface.

Apart, however, from any questions regarding the amount of heat-energy the lower air may directly contribute to the sea, or to the process of evaporation from the sea, it is to be pointed out that the Earth's atmosphere supplies energy to the ocean-surface in other important ways. Foremost is the direct transfer of kinetic energy by frictional drag of winds over slower moving waters. Wave-action is the immediate and temporary result; oceanic drift embodies the more permanent effects of this transfer of mass-energy from the atmosphere to the ocean.

The influence of wave-stirring is important as producing deeper storage of the heat-energy which enters the ocean-surface. In a completely undisturbed sea a shallow strongly heated layer must form at the surface, and this stratum be much less conservative in its rate of gain or loss of temperature than is true of the deeply stirred ocean-surface.

Another obscure but important contribution of the atmosphere to oceanic energy consists in the influence of precipitation and evaporation upon ocean-drifts. Examination of current-charts hardly supports the prevalent idea that ocean-currents are largely if not almost wholly the integrated result of average air-flow.

Cyclonic-type circulations in the ocean are exceedingly limited in extent and are usually weak in character as compared with the flow-systems of opposite type, and also as compared with the frequency and size of atmospheric cyclones. The evidence seems therefore to point very strongly to other causes of oceanic circulation than the response to the overlying wind-systems, and to indicate that the flow-responses are finally organized into great anticyclonic drifts in the seas, under the influence, mainly, of the deflective tendency resultant from the Earth's rotation.

If these views be correct, a cause of drift must be present supplementing the energy contributed by the more or less permanent wind-systems of the atmosphere. Density-differences in the ocean, causing gravity-reactions upon a world scale, provide effective energies of great power. To the maintenance of these density-differences the atmosphere contributes in a large way as follows: The fresher waters are for a given temperature, less dense than those of higher salt-content and tend to be displaced. Where rainfall is concentrated, either by direct precipitation upon the ocean-surface, or by the runoff from great watersheds, the ocean-currents show an activity that will not be found in the other, much more extensive areas of the sea-surface, where the net tendency is to extract water by evaporation and thereby increase the salinity of the sea-surface.

Much the larger portion of the total land surface of the globe drains into the Arctic-Atlantic trough, which contains the most pronounced organization of currents to be found in any of the oceans. Of this drainage, the tropical and subtropical precipitation entering the seas from which the Gulf Stream arises is a remarkable fraction of all rain falling on land within the tropical rain-belt. The Congo, the Niger, the Amazon, the Orinoco, and the Mississippi, which together comprise an unparalleled group of great rivers, all pour their fresh-water load into tropical Atlantic seas out of which the Gulf Stream, mightiest river in the oceans, originates. A coincidence, perhaps, but more likely a circumstance involving some effective relation between mass-movements in the ocean, and the salinity-density situation affected by the concentration of precipitation from the atmosphere.

Another great concentration of fresh water occurs in the Arctic Basin, into which fall the Mackenzie, and most of the great rivers of Russia and Siberia. Out of the Arctic comes the very remarkable Greenland Current, that is a main source of our own Labrador Current which is itself perhaps intensified by the reaction from fresh-water outpourings from the Hudson Bay and the St. Lawrence River drainage basins.

Where the great rivers of southern and eastern Asia flow into the Pacific and Indian oceans, and along the equatorial belt of heavy rains in the same oceans, there are also localized ocean-movements of great persistence and intensity.

The parallel between these cases of concentration of precipitation and intensification of ocean-currents is too extensive and too nearly complete to be considered anything less than strong evidence of an effective though obscure return of energy from atmosphere to oceans. The effect is of course heightened by the increase in salinity that takes place over those extensive sea-areas where evaporation into the atmosphere overbalances the rainfall received from the ocean-surface, but this influence, being well distributed over great expanses, does not provide the local contrasts in density which are necessary for great mass-movements. Those contrasts are most effectively produced by the localization of precipitation and runoff in rather definite areas marginal to the great fields of high salinity.

Whatever the importance of the obscure influence of evaporation and precipitation upon the activity of ocean-currents as here suggested, in comparison with the more obvious action of winds, it must be admitted that the major factors in ocean-movements are meteorological in character. Being so, there must be considerable inherent irregularity in the history of the relations involved. While the fluctuations of atmospheric events are no doubt greatly integrated and smoothed in the resultant oceanic circulation, it is to be expected that ocean-currents will show considerable variations

in activity. Certain currents have in fact been observed to fail entirely for some brief period of time; others are observed to occur only sporadically.

It may well be possible indeed that the rate of oceanic circulation is more significantly variable than is the history of surface-temperatures. If then, we undertake to study the thermal cargo of a major ocean-current (which certainly depends upon the volume as well as upon the temperature of the waters involved) the variations in rate of flow may perhaps be much more important than the measurable variations in temperature. The observed abnormality in the surface-temperatures of the Gulf Stream in the Florida Straits is around 3° C, and is therefore of the order of one per cent of the absolute temperature. The abnormalities in rate of flow, so far as the meager data available can indicate the variations, are of a far greater order of importance.

This brief review of the energy-exchange between oceans and atmosphere may be concluded then by reiterating the point of view expressed at the outset, namely, that the interaction between oceans and atmosphere is entirely too complicated to permit of much optimism at the present time regarding the demonstration of effective oceanographical control of weather changes from a consideration of ocean-temperatures alone. Such temperature-studies are admittedly of great importance and worthy of the most painstaking and complete investigation. Sound procedure demands, however, that temperature-fluctuations take their proper relation to the other, exceedingly important aspects of the energy-changes involved. It would seem, in fact, that an attack should be planned upon the major problem of the modes of organization and time-history of the great mass-circulations in both ocean and atmosphere to find, if we can, the symptomatic evidences that must attend those unusual accumulations of energy which are logically requisite bases of the great scale abnormalities in world weather.

U. S. Weather Bureau,
Washington, D. C.

WEATHER-CHARTS FOR THE NORTHERN HEMISPHERE

E. B. Calvert

Weather forecasting as practiced by national meteorological services is almost wholly dependent on charts prepared from observations of weather made over large areas a few hours at most before the forecasts are issued. Rapid and reliable communication facilities are prime necessities in such work. There are and must be international communication relationships to secure with dispatch the weather data composing the daily weather-maps with which nearly everyone is familiar. Few countries are large enough to depend on reporting stations within their own terrain. In this respect the United States, with its wide stretch of over 3,000 miles east and west, and about 1,600 miles north and south, in addition to its possessions in Alaska and the Pacific, is among the most fortunate of all the nations, but it could not be independent of observations from Canada and contiguous countries and be able to render wholly adequate and effective service. Most of the European countries would be helpless without exchange arrangements with other nations.

For construction of current weather-charts for the northern hemisphere there is even greater necessity for communication relationships, as well as participation by practically every nation north of the equator. Moreover, the arrangements must be definite, harmonious, and thoroughly coordinated for accurate and speedy transmissions. Northern hemisphere weather-charts worthy of being given such name were impossible 30 years ago; 15 years ago restricted charts could be and were produced, but today it is feasible to prepare comprehensive and highly creditable ones (although not ideally complete as to data and territory) showing weather conditions prevailing on the day of issue over the northern half of the world.

A little retrospect into the history of meteorology will serve to emphasize the large part that quick conveyance of information by electric devices has played and must continue to play in the development of the science. Aristotle was the first man to write a treatise on meteorology and justly should be credited with being the father of the science. Incidentally, he may be given questionable honor for the illogical

and dissonant name it bears, but we must pardon him for that, in view of the fact that since his time no one has been able to establish a better one. Aristotle's writings on meteorology were accepted as standards for more than 2,000 years after his death and very little advance was made. Of course, investigators during that period were handicapped by having very little knowledge of the atmosphere, its constituents and characteristics, and during most of it there were no mechanical means for measuring temperature, barometric pressure, etc. Nevertheless, progress was slow after Torricelli invented the barometer, after thermometers came into considerable use, and after laboratories were available. There may be many plausible explanations for such retardation but to my mind one cause stands preeminently above all others--lack of means for speedy communications. Can anyone imagine that there would have been such stagnation had communication facilities been as good then as they were even 75 years ago? Without means for exchanging information it was practically impossible for investigators to study weather occurrences and sequences at one place with those occurring synchronously in their own countries or contiguous countries.

Espy, Redfield, Loomis, and Maury are prominent names in American meteorology. Honor and glory are justly due them, as well as to Lapham and Abbe, who visioned and worked for a weather-service by our government for the benefit of the people. But action by Congress to establish a meteorological service in 1870 would not have been taken then, nor for a long time thereafter, except for a man by the name of Morse, who was not a meteorologist. Meteorology today would not have its high place among the necessary and valuable economic organizations of this and other countries of the world had not electric communications over wires and through the ether been invented. It is doubtful if any other science is so vitally dependent on these things.

Weather-maps have been constructed and used for weather-forecasting in the United States since 1868, when Abbe, through the Cincinnati Chamber of Commerce, induced the Western Union Telegraph Company to provide daily weather-reports from places along its lines. Telegraph operators served as observers and at that time the company had numerous offices in the northern and southern states. Their wires had been extended westward nearly to the Rocky Mountains and the Signal Corps was pushing its military lines far into the southwest and the northwest but very few reports were available west of the Mississippi. For many years after the meteorological service of the United States was established, weather-maps used for forecasting covered an area no greater than the range of the electric telegraph. A northern hemisphere chart of current date was not a possibility. It would not be a possibility now if dependence were placed on telegraph wires and cables. Marconi is the genius whom meteorologists must honor for having made such maps possible.

Barren wastes and frozen regions are meteorologically as important as the populated and fertile regions of the Earth. It is not to be supposed that wire-systems of telegraph, telephone, or cables would, in many years, if ever, be constructed in such areas. Monetary profit is lacking. But scientists equipped with radio apparatus will do so and, in fact, have done so. They are advancing further and further until now nearly every sparsely settled or inhospitable land in the northern hemisphere has weather observing-stations equipped with radio transmitting and receiving apparatus. Oceans constitute by far the greater portion of the surface of the northern hemisphere and have as much and as many kinds of weather as land areas. Wire-lines cannot be built over the oceans so as to contact ships. A northern hemisphere chart without weather-reports from vessels plying the vast water-expanses would be wholly inadequate.

It should not be assumed that weather-maps for the northern hemisphere on current dates are something new or that such maps are not made and published now. It is not the intention to give such impression. Many national meteorological services prepare manuscript charts of this kind twice daily and at least two, England and Germany, distribute them in printed form. Our own service, the Weather Bureau, constructs manuscript maps of this type twice daily, but they are not duplicated or published and consequently are not available to the public. It is toward the publication of a current weather-chart of the northern hemisphere daily by the United States Weather Bureau that our dreams and thoughts are directed. Now, as never before, there are sufficient data available for the production of comprehensive and satisfactory maps of this kind.

Nearly fifty years ago charts were prepared by the Weather Bureau, on which were entered weather-data for all portions of the northern hemisphere at which daily weather-

observations were made. Collections had to be by mail and consequently the maps for any data did not appear until about one year later. In July, 1876, the first published map appeared. It was of date January 1, 1874, and one appeared for each day thereafter until June 30, 1884. For some unexplained reason none was issued between July 1, 1884 and October 1, 1886. They were resumed on the latter date and continued through December 31, 1887. Publication was made in bulletin form. In addition to a chart, each daily bulletin presented detailed tabular data for every station indicated on the chart. The latter was a polar projection of very small scale, the diameter of the printed product being about eight inches. Why publication was discontinued at the end of 1887 is not clear. As the work was undertaken by the United States wholly at its expense and in accordance with plans formulated at the Meteorological Congress held in Vienna in 1873, suspension was probably due to expiration of an agreed period. General Meyer, then Chief Signal Officer, attended the Vienna meeting. He was much interested in the project and was responsible for its inauguration, but Professor Abbe suggested the program. The latter, in commenting on the bulletins and charts, stated that they were primarily intended as the basis for study of dynamics of the atmosphere and not for climatic study as such, and it is a mistake to treat them from the latter standpoint. Charts continued to be made in manuscript form until July 30, 1895, but they were never published.

Garriott summarized the daily bulletins and charts for the period 1874 to 1884 into monthly normal values and these normal charts for barometric pressure, temperature, winds, and storm-tracks were published by the Weather Bureau in 1893. Several of these charts were utilized by Bartholomew in his Meteorological Atlas, a publication which today practically stands alone in the field.

Garriott began in 1905 or 1906 to make daily charts containing data received by telegraph or cable from foreign stations, United States stations, and from ships, but the exact time is not known. They were made for his own studies and only a few have been preserved.

It is obvious that as approximately 60 per cent of the surface area of the northern hemisphere is water and 40 per cent land, no current daily map showing only weather-conditions over land areas, however complete the land data might be, could be properly designated as a weather-chart for the northern hemisphere. Consequently, opportunity for such charts was born with wireless telegraphy which has done more than any one thing toward development in practical meteorology. Incidentally, it may be stated that the first weather report received by the United States Weather Bureau by means of wireless from a ship was from the steamship New York on December 3, 1905. This was a passenger vessel plying between New York and Europe, and its position was latitude 40° north, longitude 60° west. The first report received from a ship in the Pacific Ocean was from the steamship President on June 8, 1907. It was said to be the only ship in the Pacific equipped with wireless apparatus at that time. Progress made in weather-reporting from ships by radio is indicated by the fact that the Weather Bureau received by radio 738 ship reports in 1906, about 15,000 in 1922, and about 70,000 during the past year.

On January 1, 1914, the Weather Bureau started publication at Washington of current date weather-maps of the northern hemisphere. They were lithographed on the reverse side of the regular morning map. They are believed to be the first maps of this kind published daily by any country. Much of the land and water areas of the northern hemisphere were not represented and the times of observations were not strictly synchronous. Nevertheless, the essential features of the atmospheric circulation over the northern hemisphere were fairly well depicted. It is interesting to note that millibars and degrees Centigrade were used in expressing barometric pressure and temperature, respectively. In announcing the publication, the Chief of the Weather Bureau stated that a similar manuscript map of the northern hemisphere has been prepared daily for several years in the Weather Bureau and has proved of great value to the forecasters in predicting general changes of the weather and especially in extending the periods for which such forecasts can be successfully made. He also expressed hope that "the publication of this map of the northern hemisphere will facilitate and promote the serious scientific study of the great and complex problems of the general circulation of the atmosphere." Publication of the maps in the form described continued daily until August 6, 1914, when they were stopped because of the outbreak of

the World War. Therefore, this series of northern-hemisphere charts covers a period of a little more than eight months.

After the cessation of hostilities, difficulties were encountered in reorganizing the ship and foreign exchange services. It was not until March 15, 1921, that manuscript charts were resumed, but for several months thereafter few ship reports were received.

Prior to 1922, reports of twice-daily observations were not received from stations, except in the United States, Canada, our territorial possessions, and, during the hurricane season, from the West Indies and Central America. On August 20 of that year twice-daily observations were secured from most foreign stations and two, representing respectively synchronous observations at approximately 8:00 a.m. and 8:00 p.m., were started. However, in some of the reports used the time of observation varied from one to four hours. Complete international agreement as to standard observation hours has not been accomplished, although this perplexing problem is being adjusted. Already the difficulty has been solved in major part as the result of agreements reached at the meeting of the International Meteorological Organization held in Copenhagen in 1929.

Preparation of two manuscript charts in our Washington office was made possible as a result of a visit from Captain Wehrle, head of the forecasting division of the French Meteorological Service, early in the year 1922. At that time arrangements were made for the French Service to broadcast each morning and evening a bulletin containing weather-observations taken at about 80 European stations, while the United States agreed to broadcast at 11:00 a.m. and 11:00 p.m., E.S.T., bulletins containing about 100 reports, representing the United States, Canada, Alaska, and the West Indies. Incidentally it may be said that on the part of the United States Weather Bureau this arrangement was a large magnification of a message which for more than 40 years had been cabled to France and addressed Angot Paris, Angot being the director of the French Meteorological Service when the service began. In honor of this distinguished meteorologist, long since deceased, the bulletin now transmitted twice daily is designated the Angot Bulletin, and as such has international recognition. Both the United States and France included ship observations in their bulletins. We began our part of the service on June 23, 1922, and the French on August 1, 1922. This exchange has continued until the present time, although, in accordance with understandings reached in Copenhagen in 1929, the European broadcasts were transferred to the British Meteorological Service on April 1, 1931, and the bulletins are now broadcast from the powerful British radio station at Rugby. The United States Weather Bureau transmits its bulletins through the United States Navy radio stations at Arlington and Annapolis by distant control from the Weather Bureau office. Those sent from Europe were copied by Navy operators located at Bar Harbor and repeated by land wire to the Weather Bureau offices in Washington and New York. On April 18, 1932, this copying work was transferred to Washington.

The two manuscript northern-hemisphere charts now being prepared in the Weather Bureau office at Washington are probably more complete than those issued currently and daily by any other meteorological service. Those prepared in Europe have more land and sea representation for the European land and water areas, but ours have better representation in North America, Northern Canada, the Far East, and over the Pacific, the western portion of the Atlantic, the Gulf of Mexico, and the Caribbean Sea. The largest area from which few or no reports are received lies between longitude 40° east and longitude 100° east, comprising a large part of Siberia. There are a considerable number of meteorological stations in Siberia but plans have not been worked out whereby the United States Weather Bureau or any of the European meteorological services can obtain other than a few of them early enough to be used on charts of current date.

Reports from twelve places within the Arctic Circle are received promptly and with regularity, the nearest station to the North Pole being Green Harbor, Spitzbergen.

As a rule about 200 reports from points outside of the United States are received by telegraph or radio and entered on the charts. Those, with 100 observations in the United States, selected for best geographic distribution, and over 200 reports from ships (sometimes nearly 300 a day) constitute a total of about 600 daily entries. This gives an excellent picture of the weather that is occurring and the location of

cyclones and anticyclones over the northern half of the world. Land representation by countries and stations is approximately as follows, the method of collections being indicated in parentheses.

United States	100 (Land line of Western Union Telegraph Company; contact at Toronto)
Canada	43 (Many of Canadian reports collected by radio)
Alaska	15 (U. S. Signal Corps radio system)
Greenland	5 (By radio to Toronto; land line to Washington)
West Indies	26 (Cable and Navy radio)
Mexico	20 (Cable to New Orleans; land line to Washington)
Central America	8 (Radio and land line)
Europe, Asia, Western Russia and Siberia	90 (Radio bulletins from Rugby, England)
China, Japan, and Eastern Asia	90 (By Navy radio from Manila Observatory; and by radio from USS <u>Houston</u> , China Sea)
Vessel reports	200 or more

Manuscript weather-charts of the northern hemisphere have a value far out of proportion to their relatively small cost. They would be of value to many people but it is not practicable to make them available now to anyone except meteorologists in the Weather Bureau. This is unfortunate but it cannot be helped under existing economic conditions. We must bide our time until depression has been forced out of its corner, but we cannot escape the feeling that it will not be very long before the business man whose interests lie in many parts of the world, and students and scientists concerned with meteorological problems can secure correct and comprehensive information of weather-conditions prevailing everywhere and almost as promptly as he now obtains weather-information concerning the United States. Charts of this kind will surely prove their worth and advance the cause of meteorology. It is doubtful if any plan of issue would be better than the one used in 1914. Northern-hemisphere maps published at that time were lithographed on the reverse side of the regular morning weather-map issued at Washington. This arrangement will admit of users of the map being provided with weather-information in much detail concerning the United States and Canada, and with general but substantial information concerning weather-conditions in other parts of the world in which they may have an interest. Moreover, they will have the information in their hands in graphic form within a few hours.

U. S. Weather Bureau,
Washington, D. C.

FIFTY YEARS OF NORTH AMERICAN RAINFALL

Oliver L. Fassig

To what extent does the annual rainfall vary from year to year over the North American continent? To answer this question satisfactorily it was necessary to have reliable values for the average rainfall over the continent for a period sufficiently long to include extreme variations and to have complete records for the entire area and for the same period of years throughout.

The time selected was from 1881 to 1930--50 years. A longer period would have been more desirable, but necessary records were not available in outlying regions. For the area of the United States it was a comparatively easy matter to compile reliable data. The basic values for the States and for certain selected islands of the West Indies represent regional averages, rather than averages for single localities. In the United States the average number of stations per state was about 100. The use of regional averages is a smoothing operation and most likely to reveal long-period variations in the rainfall.

The chart of average rainfall shows clearly the usual distribution of rainfall over the continent, Greenland, Central America, the West Indies, and islands in the North Atlantic. Charts were also prepared showing deviations from the average in geographical extent of rainfall for each year from 1881 to 1932. In the period of 50

years the entire continental area was never either below or above the general average during any one year; in the United States rainfall was below the average in practically the entire area in 1884, 1895, 1904, 1910 and 1917, 1924 and 1930. In 1884, 1905, and again in 1909 precipitation was above the normal over practically the entire area of the United States--but in no instance was the precipitation either entirely below or above during any single year in the past 50 years in the United States.

These annual deviations from the average or normal values show the compensating forces at work in the occurrence of rainfall, as well as the varying extent of deviations. Some interesting results are revealed in diagrams showing annual variations for 5- and 10-year cumulative departures of rainfall for the entire continental area, for the United States and for the Canadian areas. Similar diagrams were prepared for each of the states of the Union and for selected islands of the West Indies. Some of the smaller unit areas show long periods of precipitation continuously above or below the general average, but there is little positive evidence of regular recurring periods, or of steady increase or decrease over the entire period of 50 years for the continent as a whole, or for the individual states or regional areas. For the entire area of North America, as well as the area of the United States, the records show a marked period of excessive rainfall during the decade 1881-90 and two marked periods of deficient rainfall from 1891-1900 and for 1920-30.

Especially significant are the 10-year accumulated deficiencies and excesses shown in the long records of rainfall at Boston from 1818 to 1930, and on the Island of Barbados in the Lesser Antilles group of islands of the West Indies from 1841 to 1930. The Barbados record is of exceptional value as it is based upon average annual values for a large number of stations--over 100 in an area not more than three times the area of the District of Columbia. At Barbados the 10-year accumulated departures from the average of 78 years were continually below the average from 1841 to 1870, continually above from 1871-1910, and again continually and markedly below normal from 1911-30. The Boston record shows a somewhat similar swing, but differs in phase, namely, below normal from 1818 to 1850, above from 1851 to 1880, and again decidedly below since 1881.

U. S. Weather Bureau,
Washington, D. C.

ATMOSPHERIC WATER-VAPOR

Frederick E. Fowle

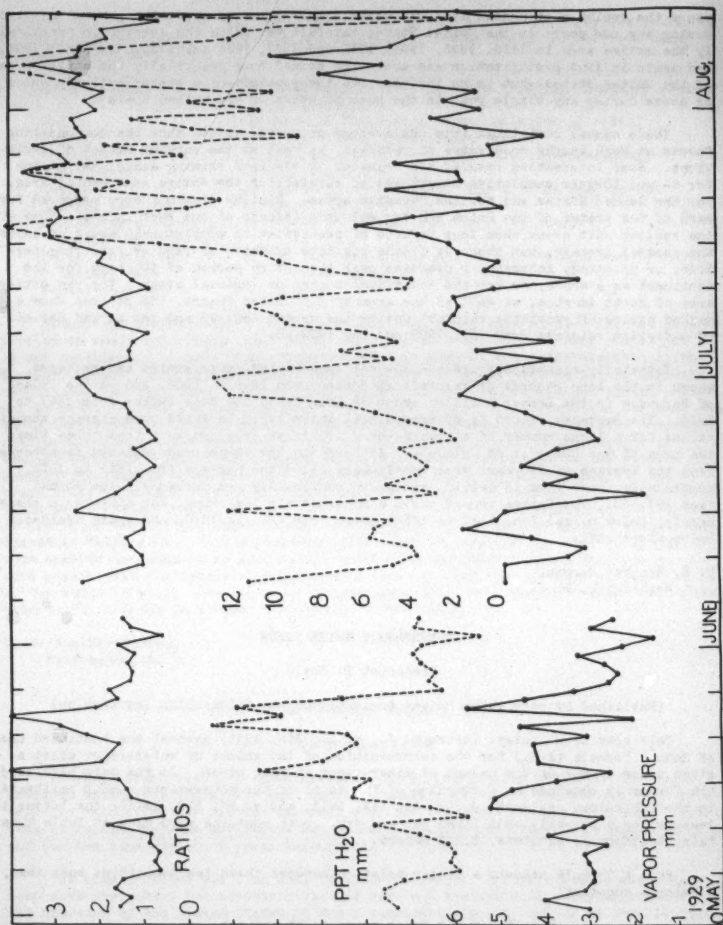
(Published by permission of the Secretary of the Smithsonian Institution)

This note is a protest (Astroph. J., v. 37, 359, 1913) against the continued use of Hann's formula (l.c.) for the determination of the amount of water-vapor above a given place by way of the amount of water-vapor at that place. In the data here used the former is obtained as a function of the depth of the water-vapor band ρ calibrated in the laboratory (Astroph. J., v. 35, 149, 1912, and v. 37, 359, 1913); the latter is measured by a properly ventilated wet and dry. Both measures were made at Table Mountain, California, altitude, 2,300 meters.

Hann's formula assumes a linear relation between these two quantities such that, K being a constant

$$\text{Ppt. H}_2\text{O} = K \times \text{vapor-pressure at surface}$$

The lower curve of the accompanying figure gives the vapor-pressure in mm at the surface of Table Mountain, the middle curve gives the precipitable water in mm for the same time, measured spectroscopically, and the upper curve gives the values of the ratio (Ppt. H_2O /vapor-pressure) or the constant K . Evidently instead of indicating K as a constant, horizontal straight line, K varies from 0.6 to 4.90, a variation of from 1 to 10. Significant features appear nearly simultaneously in all three curves so that the ratio would seem to be a function of the vapor-pressure. But the relationship is not simple.



Astrophysical Observatory,
Smithsonian Institution,
Washington, D. C.

REPORTS OF PROCEEDINGS AND DISCUSSIONS OF THE AMERICAN
GEOPHYSICAL UNION

IN THE UNITED STATES OF AMERICA

Volume 1, 1932

AMERICAN GEOPHYSICAL UNION
Thirteenth Annual Meeting

REPORTS AND PAPERS

SECTION OF TERRESTRIAL MAGNETISM
AND ELECTRICITY

Washington, D. C.
April 28, 1932

CONTENTS

	PAGE
SECTION OF TERRESTRIAL MAGNETISM AND ELECTRICITY.	143
Reports on magnetic and electric work of organizations in the United States during 1931-32.	145
Summary of reports received. Harlan W. Fisk.	145
Auroral station at the Alaska Agricultural College and School of Mines. Veryl R. Fuller.	147
Work of the Bell System relating to terrestrial magnetism and electricity during 1931. Otto B. Blackwell.	148
Magnetic investigations of the Carnegie Institution of Washington May 1931 to April 1932. J. A. Fleming.	148
Researches at Mount Wilson Observatory of the Carnegie Institution of Washington relating to terrestrial magnetism. Seth B. Nicholson.	153
Colorado School of Mines. C. A. Heiland.	153
Massachusetts Institute of Technology.	153
(a) Cooperation in the cosmic-ray survey. Ralph D. Bennett.	153
(b) The elimination of night-course variations in radio range-beacons. W. G. Kear.	154
(c) Developments in geophysical prospecting by electrical-potential methods. W. Spencer Hutchinson.	154
Solar-constant work by the Smithsonian Institution. C. G. Abbot.	155
Research in atmospheric electricity at the Stanford University. Joseph G. Brown.	155
Geophysical work at the United States Bureau of Mines. Scott Turner.	155
Magnetic work of the United States Coast and Geodetic Survey. R. S. Patton	156
Work of United States Hydrographic Office in terrestrial magnetism and electricity. W. R. Gherardi.	157
Work related to terrestrial magnetism and electricity of the Naval Research Laboratory. E. D. Almy.	158
United States Signal Corps. G. E. Kump.	158
Papers.	159
On calculations of the ionization in the upper atmosphere. E. O. Hulburt.	159
The geophysical significance of radio measurements of the ionized layer. M. A. Tuve.	160
Radio exploration of ionization of the upper atmosphere. J. H. Dellinger.	166
Kennelly-Heaviside-layer measurements on the Byrd Antarctic Expedition, 1929-30. Malcolm P. Hanson.	167
Some common periodicities in radio transmission-phenomena. G. W. Kenrick and G. W. Pickard.	172
Progress in the studies of cosmic correlations with radio reception at the Perkins Observatory. Harlan T. Stetson.	180
Slow-moving ions in the atmosphere. G. R. Wait and O. W. Torrason.	182
Principles of a new portable electrometer. Ross Gunn.	187
Optically-compensated variometers and wide-range recorders to be used during the Jubilee Polar Year. H. F. Johnston.	187
The relation of lightning-discharges to changes in the electrical field of thunder-storms. J. C. Jensen.	190

REPORTS ON MAGNETIC AND ELECTRIC WORK OF ORGANIZATIONS IN THE UNITED STATES DURING 1931-32

SUMMARY OF REPORTS RECEIVED

Harlan W. Fisk

Individuals and organizations known to be engaged in geomagnetic or geoelectric investigations were invited to submit brief summaries of the work done during 1931-32 or synopses of the problems under discussion, and to this invitation a considerable number have responded. Papers were submitted by the following organizations and are therefore not included with Reports or in this summary: Nebraska Wesleyan University, Ohio Wesleyan University, Tufts College, and Bureau of Standards. In general the work of all investigators has been a continuation of that reported at the twelfth annual meeting of the Union with evidence of definite progress in most cases. These brief statements are given in full in the succeeding pages but for convenience a general survey of the field covered is presented in the following summary arranged according to subject-matter.

Magnetic observatories--The five magnetic observatories of the United States Coast and Geodetic Survey have continued in operation without serious interruption. Some improvements in instrumental equipment are reported, particularly with respect to temperature-control, and in the case of Sitka for the purpose of securing continuity of records during large magnetic storms. The two magnetic and electric observatories of the Carnegie Institution of Washington--Watheroo in Western Australia and Huancayo in Peru--have been maintained. Registrations of variations of declination and horizontal intensity have been made at Mount Wilson for the purpose of comparing solar and magnetic activity.

Magnetic standards--The control of the provisional International Magnetic Standards of the Department of Terrestrial Magnetism has been further undertaken by that Department by means of intercomparisons during the year between its standards and those of the United States Coast and Geodetic Survey at San Juan, Porto Rico, of the National Observatory at Vassouras, Brazil, of the Meteorological Service at Pilar and La Quisaca, Argentina, and of the Observatory at Lukiapang, China. Partial comparisons have also been made with the instruments in use at Bergen, Norway, and at Santiago, Chile.

Magnetic surveys--Only the United States Coast and Geodetic Survey and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington are so organized as to undertake extensive magnetic surveys. The former reports extensive work in the United States with additional work along the coasts of Hawaii, Alaska, and the Philippines in connection with hydrographic surveys. The latter has under way two extensive expeditions covering the West Indies and South America, besides some cooperative work in China and Africa. The Hydrographic Office of the United States Navy is undertaking the systemization of the international exchange of surveys and observations by the members of the Bureau at Monaco.

Magnetic discussions--Aside from the large variety of problems which have received attention during the year at the Department of Terrestrial Magnetism of the Carnegie Institution which are more fully reported by the Acting Director of that Department, attention has been chiefly directed to the effects of changes in magnetic field on various aspects of the problem of communication, and to applications on magnetic data and distribution to the location of ore-deposits. The Bell System has carried on observations particularly with reference to the fluctuations of earth-potentials and to the variations of the radio ceiling which correlate with magnetic disturbances; while the Bureau of Mines and the Colorado School of Mines have given special attention to the distribution of the permanent magnetization of various regions and its bearing on geological structure.

Magnetic instruments--The question of temperature-control in magnetic instruments has received recognition as of great practical importance. At most of the observatories compensating-devices have been installed on the magnetographs. It has been made an

especial feature of the instruments specially devised for the Polar-Year observations, and Dr. Heiland and W. E. Pugh of Colorado report a new system for the Askania field-balances truly unaffected by temperature over a wide range and in fields of widely varying inclination.

Experimental work has been under way by Soule of the Department of Terrestrial Magnetism of the Carnegie Institution for the development of more accurate instruments for use on moving vessels at sea or in the air, and also for designing improved electro-magnetic magnetometers.

Earth-currents--Registrations have been continued at Watheroo and Huancayo by the Department of Terrestrial Magnetism of the Carnegie Institution and, in cooperation with the United States Coast and Geodetic Survey, the Mountain States Telephone Company, and the American Telephone and Telegraph Company, similar work has been carried on at Tucson, Arizona. Records of earth-potentials have been continued at New York City as during the past four years; other recorders are in operation at Houlton, Maine, and at Wyand, Illinois, and a fourth point also is proposed for the Polar Year.

Atmospheric electricity--Observations of air-potential and air-conductivity have been continued by the Carnegie Institution at Washington, D. C., at Watheroo, Western Australia, and at Huancayo, Peru. Cooperation has been extended by them to the Apia Observatory, Western Samoa, and to the Christchurch Observatory, New Zealand, to insure complete magnetic and electric programs there. Cooperation has also been extended to the United States Coast and Geodetic Survey, by which records are being obtained from Tucson, Arizona. Continuous records of potential gradient are being made by Brown at Stanford University.

Space-charge--At Stanford University continuous records of space-charge are being taken at two levels, namely, (1) near the surface, and (2) 16 meters above, in accordance with plans announced last year.

Lightning--The work of Prof. Jensen of Nebraska Wesleyan University presents evidence on the subject of polarity and thunder-clouds which bears upon the difference in the theory of G. C. Simpson and C. T. R. Wilson. His argument is presented elsewhere in these Transactions. At Stanford University, E. A. Evans is carrying on experimental work in the laboratory to establish a theory of the mechanism of the lightning-stroke.

Thunder-storms--The Hydrographic Office, with the assistance of the Naval Research Laboratory, is continuing the attempt to locate storm-centers by means of static recorders. An attempt will be made to track a storm across the United States by means of bearings on its attendant atmospherics. By similar methods an attempt will be made to locate the centers of West Indian hurricanes.

Ionization--Wait and Torreson of the Carnegie Institution have developed a continuous record of large positive ions, a discussion of which forms a subject of a paper on this program. E. O. Hulburt of the Naval Research Laboratory completed, as far as present data permit, the work on the ionization of the high atmospheric field giving tables of the ionization over the Earth. Ralph D. Bennett of the Massachusetts Institute of Technology will carry out measurements of cosmic-ray intensity at two altitudes in Alaska, California, and Colorado, from which it is hoped to obtain information regarding ionization due to cosmic rays. This work is done in connection with the cosmic-ray survey conducted by A. H. Compton.

Aurorae--Systematic observations of the height of aurorae have been continued by V. R. Fuller at Fairbanks, Alaska, during the dark hours. E. O. Hulburt of the Naval Research Laboratory has examined available records of aurorae and substantiated Veillard's conclusion regarding frequency of the various forms during morning and evening hours.

The Kennelly-Heaviside layer-height--Much work is being done in studying the behavior of the radial ceiling and its variations in apparent correlation with geophysical and other cosmic phenomena. The technique for measuring these heights has been well developed by the Bureau of Standards and apparatus for continuously recording these heights is being constructed by the Carnegie Institution in cooperation with the Bureau of Standards for use during the Polar Year. Investigations made by the Bell

System seem to indicate that the height of reflecting layer over the Atlantic differs materially from that over the Pacific. Other studies by the Bell System are designed to give more direct information concerning the height and direction of arrival of received signals. At the Massachusetts Institute of Technology experiments are being made with a new type of range-beacon by which it is hoped to eliminate the uncertainty of the behavior of radio compass due to the polarisation of reflected waves during the hours of darkness.

Correlations--The problem of determining the relation of fluctuations in geomagnetic and geoelectric phenomena with solar and lunar changes has received a large amount of attention. C. G. Abbot of the Smithsonian Institution has continued the measurement of solar radiation at his stations in California and in Chile, but the station in Africa has been discontinued. He has examined the data obtained in the endeavor to find definite periods of fluctuation. H. T. Stetson at Perkins Observatory has continued the examination of radio reception to establish a correlation with a lunar period. Kenrick and Piskard have used similar data for the study of changes in signal-intensity. The Signal Corps of the War Department has noted a consistent change in the high frequency-transmission results corresponding to the solar cycle.

Earth-resistivity and geophysical prospecting--The Colorado School of Mines reports the establishment of a lecture and laboratory course on the use of various magnetic and electric methods of prospecting. Tatam and Manhart have nearly completed their work on electrical prospecting by the resistivity-method, the field work having been done in Texas and Colorado. At the Massachusetts Institute of Technology a study has been made of equipotential prospecting with miniature models in the laboratory with very gratifying results. Resistivity-surveys have been made by the Bureau of Mines to correlate, if possible, oil and gas structures with resistivity-measurements. Simplified designs of geophysical apparatus are being constructed with a view to increasing their value of application by reducing the cost of manufacture.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

Auroral station at the Alaska Agricultural College and School of Mines

Investigation in the field of terrestrial magnetism and electricity with the allied subjects has been rather limited at the Alaska Agricultural College and School of Mines. To date only two lines of investigation have been attempted, a study of the aurora borealis and a systematic recording of short-wave radio reception.

The work on the aurora consists mainly of the determination of its height above the surface of the Earth and its position in space. This work is done by means of the photographic method of determining parallax. So far over 160 negatives have been secured which are suitable for measurement. The equipment, consisting of two special cameras, purchased in Norway, is similar to that used by Professor Stormer and others engaged in this work. The study of the aurora was made possible by assistance given by the Carnegie Institution and the Rockefeller Foundation.

In addition to this a watch is maintained at half-hour intervals, during the hours of darkness, to secure data to be used in the URSigrams and to be used later in a correlation of these with other natural phenomena.

Twice daily, at 08:00 G.M.T. and 17:00 G.M.T., time is received from NAA at Arlington and data regarding reception is carefully noted. These data include an estimate of signal-intensity and fading and also include the general weather-conditions existing at the time. Although at present no attempt is being made to compare these data with those taken at any other station, they may at some time prove of some value.

Veryl R. Fuller,
Professor, Department of Physics

College, Alaska, April 6, 1932

Work of the Bell System relating to terrestrial magnetism
and electricity during 1931

The Bell System has for several years been studying certain terrestrial phenomena and their relation to communication. This study has for the most part centered around the correlation of transoceanic radio transmission with magnetic storms, earth-potentials, and allied phenomena. A more complete review of the work done to March 1, 1931, was given in a memorandum on this subject dated March 2, 1931. The report below is intended to bring that information up to date.

Records of earth-potentials--Earth-potentials have been recorded in the vicinity of New York City for about four years. The major storms noted have been accompanied by marked depressions of signal-strength from distant short-wave radio stations. A paper establishing a correlation between such disturbances and both long-wave and short-wave radio transmission has been published (Proc. I.R.E., v. 19, pp. 1931-1947, 1931).

The grounds obtainable near New York City were adequate to show the major disturbances but industrial interference precluded an estimate of the normal diurnal-variation. To meet this situation and to provide a more complete picture of the effects of earth-conductivity and position, recorders have recently been set up at Wyand, Illinois, and at Houlton, Maine. At the former point the test-lines are in cable and extend eastward and southward, respectively, 73.2 kilometers and 58.4 kilometers. Industrial disturbances have been sufficiently reduced to detect the normal diurnal-variation. Insufficient information is yet at hand to evaluate this variation.

At Houlton, Maine, the test-lines are in open wire and extend southward 51.3 kilometers to Danforth, Maine, and east southeastward 46.3 kilometers to Southampton, New Brunswick. Conditions here also are favorable for measuring the normal diurnal-variation. A fourth recording-point located in the east will probably be set up before the beginning of the Polar Year.

Radio measurements--The normal operation of the transoceanic radiotelephone-circuits entails frequent measurement of the field-intensity of signals from distant stations. Measurements of transatlantic stations have been in progress for several years. During 1931 these measurements were extended to include several Pacific stations as received near San Francisco. Marked differences between transmission over the Pacific and over the Atlantic suggest corresponding differences in the Kennelly-Heaviside layer over these areas. Aside from the measurements incidental to the operation of radio circuits there are other studies in progress designed to give more direct information concerning the nature of the Kennelly-Heaviside layer. Principal among these are height-measurements and direction of arrival of received signals. Reports on these studies have appeared from time to time in the Proceedings of the Institute of Radio Engineers. It is expected that others will be published as the work progresses.

Otto B. Blackwell,
Transmission Development Engineer

Bell System,
American Telephone and Telegraph Company,
New York, New York, March 24, 1932

Magnetic investigations of the Carnegie Institution of Washington
May 1931 to April 1932

Laboratory investigations

Magnetic disturbances and diurnal variation--Investigation of magnetic disturbances in different latitudes was continued. Previous studies indicated that in world-wide magnetic storms the greatest disturbances on the Earth's surface occur in the region of the zone of maximum auroral frequency. Assuming as a cause a ring or vortex of moving ions above the auroral zone, Wallis, using data from arctic and other observatories, made efforts to locate the position in space of such a feature. The results of the analysis thus far seem to be inconsistent with this theory, but this may be due to unsteadiness of the assumed current or to the complicated effects of currents induced within the Earth.

The homogeneous series of monthly means of terrestrial-magnetic activity 1872-1930 was discussed by Bartels in its relation to solar activity using new tests for periods. Only a semi-annual wave in magnetic activity is recognized as physically significant; its maxima prefer the times when the Sun is in the celestial equator and not, as has been suggested, the times when the Sun's axis is most inclined towards the ecliptic. The close relation between sunspot-numbers and terrestrial-magnetic activity in the annual and monthly means was discussed, and some general statistical aspects were given for the treatment of correlation between such series with after-effects for which both solar activity and terrestrial-magnetic activity are typical.

The individual 27-day recurrences in terrestrial-magnetic activity during 1906-31 and their relations to solar activity were discussed using a graphical day-by-day record. This investigation indicates the existence of persistent active areas on the Sun's surface which have been designated M-regions and which in many cases cannot be coordinated to solar phenomena such as are observable by direct astrophysical methods. Thus observations of terrestrial-magnetic activity yield not only information about geophysical influences of those phenomena that may be traced in astrophysical observations but supplement these direct observations themselves.

The annual mean values of horizontal intensity from the records of 25 observatories during 1903-27 were investigated by Fisk to determine any common fluctuations in apparent secular rate conforming closely to the sunspot-cycle, as to the extent the fluctuations are world-wide or regional in character, and as to whether it might be possible to detect world-wide effects not conformable to the sunspot-cycle. The results indicate that a large portion of the irregularities in the apparent secular rate of horizontal intensity are connected with the after-effects of magnetic disturbances; that the effects are world-wide though the magnitude of the departures indicated are connected in some way with geographic position and also, when expressed in absolute units, with the magnitude of the component; that the regional characteristics may be of such a character that their effects are compounded with those of the after-effects of storms; and that occasional outbursts not in step with the 11-year cycle may introduce irregularities out of phase with the general period. The possibility is also indicated that there are other periods than the 11-year period which by combination produce a resultant curve which may appear as a lag in the principal period.

The determination and analysis of the magnetic lunar diurnal-variations from the data obtained at the Watheroo and Huancayo magnetic observatories were begun.

Magnetic activity--The measure of magnetic activity adopted for trial at the 1930 meeting of the Association of Terrestrial Magnetism and Electricity of the International Union of Geodesy and Geophysics, namely, $(HR_H + ZR_Z)/10,000$, was computed from the data at the Watheroo and Huancayo magnetic observatories for 1929, 1930, and 1931. A discussion by Duvall of the results for 1929 and 1930 in comparison with the u -measure indicates this trial-measure to have a marked variation due to seasonal change. A like discussion of these activity measures for 1930 determined from the data at the five observatories of the United States Coast and Geodetic Survey is in progress.

Magnetic secular-variation--A more rigorous discussion of the magnetic secular-variation from the many data accumulated during the ten cruises of the Galilee and of the Carnegie than the preliminary discussions by Ault and by Johnston was begun by Fisk. So far as practical, the method used is that of adjusted groups of observed values by least squares to eliminate relatively large error in individual determinations. The method not only improves considerably the consistency of secular rates determined but also provides a basis for estimating the degree of accuracy for observations at sea and for detecting such systematic errors as may be due to dynamical deviations and tilting of the vessel.

Compass-deviations produced by ship's motion--With the completion in January of the special automatic swing, and motion-picture apparatus, experiments on compass-deviations produced by ship's motion were begun by Peters. So far non-magnetic bars or needles are being used to investigate the magnitude and sense of the centrifugal couple which is one of the components in the deviation of compasses caused by the motion of a vessel at sea. Thus far the results indicate fair agreement between experiment and the formula based upon simplifying assumptions. The sense of the couple is the same as that of the dynamic-deviations discussed by Bidlingmaier (Deutsche Sudpolar

Expedition, 1901-1903, Bd. V; Erdmagnetismus, Bd. I, Heft 2, I. Teil, pp. 273-309, Berlin, 1909) and also that of the tilting deviations already investigated by the Department of Terrestrial Magnetism (W. J. Peters, Terr. Mag., v. 34, 93-115, 1929). The experiments show a deviation which could be eliminated with sufficient precision in the case of uniform rolling by using one or the other set of extreme readings in a long set if the deviation were caused only by the centrifugal couple. Preliminary experiments were also made with varying amplitudes of the swing-motion which resemble ship motion more closely. The mathematical treatment of this condition will probably be too complicated, but the experiments indicate that even under this condition the deviation might be reduced by omitting certain extreme values.

Atmospheric electricity--Investigations by Wait and Torreson in connection with the reduction of atmospheric-electric conductivity records from the observatories have taken account of temperature-coefficient of apparatus, temperatures to which subjected, and scale-value and calibration data.

In the continuation of the study of atmospheric pollution and its relation to atmospheric electricity, Wait and Torreson, after preliminary series of eye-reading observations, developed continuous recording of large positive ions, this apparatus being in use since March 1, 1932. The discussion thus far of the data obtained may be outlined as follows: (A) Character and nature of the large ion as shown by (1) relation between condensation-nuclei and large ions, (2) diurnal variation of large ions, and (3) comparison of diurnal variation of large ions on fair days with that on rainy days. (B) Part played by large ions in atmospheric electricity as shown by (1) charge per large ion, (2) ratio of positive to negative large ions, (3) relation of large ions to small-ion conductivity through calculated rate of production of small ions, and (4) the distribution of the number of large ions according to mobility.

Investigations of the relationship of the atmospheric-electric data obtained at the observatory in Washington and meteorological factors have been made by Gish and Sherman.

Earth-currents--The discussion of earth-current data obtained at the Watheroo and Huancayo magnetic observatories has been continued by Gish and Rooney. In 1930 the series at Watheroo continued satisfactorily as in the past although some difficulty was encountered owing to the high contact resistance at the electrodes during the dry season. The data from Huancayo were considerably improved by the changes made in electrode positions during 1929 and 1930. Aside from loss due to frequent thunder-storms, the operation of the system there has been most satisfactory. The general features of the earth-current variations indicated by the continued discussion of the data are the same as those previously reported at both observatories.

Gish has continued his study of earth-resistivity methods and data.

Improvements for more economical compilations of data for discussion--The necessary apparatus for practical utilization of the photographic method to reduce the ratio of ordinate to abscissa scale for photographic records developed by Peters and Green as indicated in last year's report is in construction. Harmonic analysis with sufficient accuracy of certain of the data in discussion has been greatly facilitated through the use of a harmonic analyzer designed and constructed by Mader in Germany. This analyzer has been extensively used during the year.

Atomic and nuclear physics--The experiments with vacuum tubes operated at potentials above one million volts have been continued by Tuve, Hafstad, and Dahl. This work has as its aim the study of the simplest conceivable cases of electric and magnetic interaction, namely, the interaction of electrons and protons and their least complex combinations, especially the lighter atomic nuclei. These two simplest units show both magnetic and electric properties, and their interactions constitute the most fundamental problems of electricity and magnetism. Their closest combinations represent very high binding-energies, hence the direction taken in this research. Since the last report the chief progress, in addition to developments of technique and instruments, has been the production and measurement of high-speed protons (hydrogen nuclei) to be used as projectiles for studies of the interactions involved in very close collisions. These experiments have included the unambiguous detection and measurement of the proton-rays and the photographing of their tracks, yielding a preliminary measure of the range-

velocity relation for these artificially produced "H-rays." Preparation for studies of nuclear scattering of protons includes the calculation by Loveridge of a set of tables giving the predicted inverse-square scattering and the application of the FP-54 electrometer plictron to the detection of single alpha- and H-particles. Tests of the Van de Graaff electrostatic generator are in progress as a part of the search for a suitable laboratory source of steady high potentials to replace the fluctuating Tesla voltages.

Observatories--The magnetic, atmospheric-electric, earth-current, and meteorological observations at the Watheroo and Huancayo observatories have been continued by Observers-in-Charge Parkinson and Ledig and their staffs. Atmospheric-electric observations of air-potential and air-conductivity have been continued in the desk observatory at Washington and, in cooperation with the United States Coast and Geodetic Survey, at the Tucson Magnetic Observatory. The recording of earth-currents at Tucson made possible by the cooperation of the American and of the Mountain States Telephone and Telegraph companies with the Survey and the Department as reported last year has been continued; it is expected that except for unforeseen commercial requirements of the lines in use this work will be continued at least to the end of the Second International Polar Year, namely, August 31, 1933.

The cooperation with the Apia Observatory was continued to insure complete magnetic and electric programs there, as well as at the Christchurch Observatory in New Zealand.

Spectroheliscopes were received from the Mount Wilson Observatory at both the Watheroo and Huancayo observatories, and the necessary buildings for their installation have been constructed. The spectroheliscopes are now being adjusted at both observatories for regular observation.

Complete radio equipment has been provided and installed and necessary buildings constructed at the Huancayo Magnetic Observatory to insure the development of an extensive radio program there, as also at the Watheroo Observatory, for the study of correlations of radio transmission and receiving conditions with magnetic and electric phenomena.

Work at land stations and cooperation--Observations in the field during the past year have included the occupation of two stations in Norway, one station in Spitsbergen, and one station on the ice during the cruise of the *Nautilus* in the Arctic Ocean. Comparisons were made at Lukiapang and at Wuchang, China, in preparation for field work in cooperation with the Central China College.

More intensive work has been done in the West Indies and South America, where two expeditions have been in the field since August. J. W. Green visited the magnetic observatories at San Juan, Porto Rico, at Vassouras, Brazil, and at Pilar and La Quiaca, Argentina, where magnetic standards were compared, and in addition he occupied stations en route for secular variation. At present he is on his return by way of Bolivia, Chile, and Peru. An important part of his mission has been to visit as many as possible of the organizations and individuals interested in geophysical investigations in the countries along his itinerary with a view to encouraging so far as possible increased activity in magnetic work. Earl Hanson accompanied Green to the West Indies as far as Porto Rico and has since been engaged in reoccupying magnetic stations in Venezuela and Brazil along the Orinoco and the Amazon and its tributaries. This expedition traversed one of the regions within which the rates of secular variation show extremely interesting characteristics. A discussion of the results of the observations taken on these expeditions is under way.

A great deal of attention has been devoted to forwarding the project for the Second International Polar Year and the participation in that effort by the United States Government. Variometers suitable for use at one of the stations proposed and for increasing the program of work at the Watheroo and Huancayo observatories during the Polar Year have been purchased by the Institution. These instruments, with the cooperation of the Coast and Geodetic Survey, have been under test at the Cheltenham Magnetic Observatory. In addition there have been constructed, bearing in mind especially the electric and radio programs indicated for the Polar-Year effort, special automatically recording conductivity-apparatus and special apparatus for determining continuous-

ly the height of the Kennelly-Heaviside layer, the latter being in cooperation with the United States Bureau of Standards. Earth-current apparatus suitable for use at Polar-Year stations has been developed and tested by Gish and Rooney at Washington.

The experimental work by Soule on the earth-inductor method of measuring the magnetic intensity of the Earth's field for the development of a more accurate and more rapid employment of this method at sea was interrupted by his participation in the Wilkins-Ellsworth Trans-Arctic Submarine Expedition but is now being continued. The development has been carried on having in mind the use not only on surface vessels but also on lighter-than-air carriers. Preliminary designs have also been made for electromagnetic magnetometers for work on land, and for a remote-controlled, remote-reading, electromagnetic instrument for measuring intensity and inclination for use at sea in a submerged container placed at a distance from a magnetic vessel.

Publications

The following is a list of the more important papers published in the past year:

- Adams, L. H., and J. W. Green. The influence of hydrostatic pressure on the critical temperature of magnetization for iron and other materials. *Phil. Mag.*, vol. 12, 361-380 (Aug. 1931); *Terr. Mag.*, vol. 36, 161-169 (Sept. 1931).
- Bartels, J. Geophysical stereograms. *Terr. Mag.*, vol. 36, 187-198 (Sept. 1931).
- , Terrestrial-magnetic activity and its relation to solar phenomena. *Terr. Mag.*, vol. 37, 1-52 (1932).
- , and W. J. Rooney. A typical case of variability of quiet-day diurnal variation in terrestrial magnetism and earth-currents at Watheroo. *Terr. Mag.*, vol. 37, 53-55 (1932).
- Bauer, L. A., and J. A. Fleming. Annual report of the Director of the Department of Terrestrial Magnetism, Carnegie Inst. Wash. Year Book 30, 1930-1931, 281-370 (1931).
- Davies, F. T. Observations of the aurora australis, Byrd Antarctic Expedition, 1929. *Terr. Mag.*, vol. 36, 199-250 (Sept. 1931).
- Duwall, C. R. Magnetic activity--some results of the measure adopted at Stockholm. *Terr. Mag.*, vol. 36, 311-314 (Dec. 1931).
- Ennis, C. C. Magnetic secular variation for epoch 1930. *Terr. Mag.*, vol. 36, 315-317 (Dec. 1931).
- Fisk, H. W. Magnetic secular variation and solar activity. Internat. Res. Council, Third Rep., Comm. Solar and Terrestrial Relationships, 52-59 (1931).
- Fleming, J. A. Researches of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington bearing on solar activity and the Earth's magnetic and electric fields. Internat. Res. Council, Third Rep., Comm. Solar and Terrestrial Relationships, 60-64 (1931).
- , The proposed second International Polar Year 1932-1933. *Geog. J.*, vol. 22, 131-134 (Jan. 1932).
- , Summary of the year's work, Department of Terrestrial Magnetism, Carnegie Institution of Washington. *Terr. Mag.*, vol. 36, 333-339 (Dec. 1931).
- Gish, O. H. Systematic errors in measurements of ionic content and the conductivity of the air. *Beitr. Geophysik*, vol. 36, 1-5 (1932).
- Harradon, H. D. List of recent publications (terrestrial and cosmic magnetism, terrestrial and cosmic electricity, miscellaneous). *Terr. Mag.*, vol. 36, 161-160 (June 1931); 264-271 (Sept. 1931); 367-373 (Dec. 1931); vol. 37, 93-102 (Mar. 1932).
- Huff, C. Automatic time-delay relay. *Proc. Inst. Radio Eng.*, vol. 19, 1019-1020 (June 1931).
- Paul, J. H. The last cruise of the Carnegie. With a foreword by John A. Fleming. Williams and Wilkins Co., xiii + 351 with 198 illus. (1932). Baltimore.
- Peters, W. J., and J. W. Green. A photographic method of changing the ratio of ordinate-scale to abscissa-scale. *Terr. Mag.*, vol. 36, 99-104 (June 1931).
- Torreson, O. W. The determination of geographical position for scientific observations at sea and especially in connection with magnetic work. *Hydrogr. Rev.*, vol. 8, 112-113 (Nov. 1931).
- Wait, G. R. Diurnal variation of concentration of condensation-nuclei and of certain atmospheric-electric elements at Washington. *Terr. Mag.*, vol. 36, 111-131 (June 1931).
- , and O. W. Torreson. Rate of ionization of the atmosphere. *Nature*, vol. 129, 401-402 (Mar. 12, 1932).

J. A. Fleming,
Acting Director

Washington, D.C., April 28, 1932

Researches at Mount Wilson Observatory of the Carnegie Institution
of Washington relating to terrestrial magnetism

Continuous records of horizontal intensity and declination have been continued at Mount Wilson during the past year. Magnetic character-figures have been estimated from these records and published regularly in Terrestrial Magnetism and Atmospheric Electricity with the character-figures representing solar activity. A comparison of solar and magnetic activity has been made in the notes accompanying the tables of character-figures. No further results or conclusions have been reached since the report of last year.

Seth B. Nicholson

Pasadena, California, April 7, 1932

Colorado School of Mines

In regard to research work under way at this School, the following may be of interest:

- (1) Thesis for the Doctor's degree in geophysics by George B. Somers, "Correlation of the anomalies of vertical intensity of the Earth's magnetic field with the regional geology of North America. Reprints are available from the Director of Publications of the School.
- (2) "Electrical prospecting by the resistivity-method" by Maurice Tattam and T. A. Manhart. This work is nearing completion and covers a complete study of the theory of such measurements as applied in geophysical structural studies, especially as to the interpretation of results and location of the depth to discontinuities. The studies have been checked by numerous laboratory tank-experiments and field work near El Paso, Texas, where the geologic section was known, and by field work in Colorado.
- (3) Tests conducted by C. A. Heiland and W. E. Pugh on the new zero temperature-coefficient magnetic system for vertical field-balances, developed by the Askania Company, will appear shortly as a technical publication of the American Institute of Mechanical Engineers. These tests proved the new system as truly unaffected by temperature, even over a wide range or by changes in dip of the Earth's field, such as would take place with change in latitude.

C. A. Heiland,

Golden, Colorado, March 22, 1932

Professor, Department of Geophysics

Massachusetts Institute of Technology

(a) Cooperation in the cosmic-ray survey

In connection with progress-reports of work being carried on in the study of atmospheric ionization I should like to mention my plan to conduct the Alaska, California, Colorado Expedition of the Carnegie Institution's cosmic-ray survey this summer.

I shall take rather extensive measurements of cosmic-ray intensities at two altitudes each in Alaska, California, and Colorado. It is hoped that these observations will yield information on (1) relative values of ionization at different heights, (2) diurnal variation of ionization due to cosmic rays, and (3) variation of ionization with latitude.

In addition I hope to repeat the Bothe-Kolhorster Geiger counter-experiment at a high altitude in Colorado. This should measure directly the absorption-coefficient of the softer components of the ionizing rays which set off Geiger counters, and will, it is hoped, throw some light on the nature of the cosmic radiation.

I should like to call attention to the fact that this is merely a part of an extensive survey carried on under the direction of A. H. Compton and may have been reported already to you.

Cambridge, Mass., March 28, 1932

Ralph D. Bennett, Associate Professor,
Department of Electrical Engineering

(b) The elimination of night-course variations in radio range-beacons

It has long been known that the effect of the Kennelly-Heaviside layer during the hours of darkness is such that radio compass-bearings are unreliable unless special antennas are employed. A similar error is introduced when the cross-coil radio-beacon is used for night flying. This error, which manifests itself as a short-period swinging of the on-course zone over angles in excess of 90° , is due to a multiplicity of causes. The predominating sources of error, however, seem to be rotation of the plane of polarization of the original signal and a shift in phase of the frequency-components of the modulated wave.

At Round Hill a new type of range-beacon is being experimented with, which, it is hoped, will reduce the errors to a negligible amount. The crossed loops are replaced by two vertical towers. These are excited by transmission-lines suitably phased so that two cardioid patterns are produced. These cardioids intersect and are furnished each with a characteristic code-letter so that the intersection forms the equisignal zone or beacon-course.

The radiated wave from this array is vertically polarized, no horizontally polarized components being sent out. While the vertical components will undoubtedly be rotated, it is the originally horizontally polarized components which cause most of the error; hence a considerable reduction should be secured by this change.

In addition the use of two towers rather than crossed loops means that on the course the signal will be received from two equidistant antennas. Both signals are generated by an array occupying the same plane. This also should reduce the error.

Experimental work has not yet progressed to a point where any definite conclusions can be drawn.

N. G. Kear

Cambridge, Massachusetts, April 8, 1932

(c) Developments in geophysical prospecting by electrical-potential methods

Regarding work done in the Department of Mining and Metallurgy relative to terrestrial magnetism and electricity, I quote from a statement prepared for me by Prof. Foster:

"The Department, during the past year, has carried on investigations in the field of electrical prospecting. These consisted of laboratory and field studies of equipotential methods.

"The first investigation involved the development of apparatus which would permit of small-scale experiments in the laboratory and the determination of the optimum spacing of ground-contacts with the linear electrode-system of equipotential prospecting. Laboratory work was carried on at Massachusetts Institute of Technology, and the results checked on a larger scale in the vicinity of Buchans, Newfoundland.

"Secondly, a study was made of equipotential prospecting with miniature ore-bodies using the apparatus above mentioned. Highly conductive models in several attitudes were buried in sand at varying depths, the equipotential lines traced being photographed for permanent record. The results show that laboratory work can be used to assist in the interpretation of field results.

It was my own observation while the work mentioned above was going on that the results gave promise of something really worth while in the field of miniature experiments to assemble data for interpretation of field work.

W. Spencer Hutchinson

Professor, Department of Mining and Metallurgy

Cambridge, Massachusetts, April 7, 1932

Solar-constant work by the Smithsonian Institution

The Astrophysical Observatory is publishing Volume V of its Annals, containing the results of observations on the solar constant of radiation made in California, Chile, and Southwest Africa, from 1920 to 1930. The volume has passed through page-proof and may be expected to issue at any time.

Progress has been made in the discovery of regular periodicities in solar variation, and a special machine, called the Periodometer, has been constructed for discovering and evaluating such periodicities and corresponding ones in weather-departures. Interesting results are being obtained with this instrument but are not as yet in condition to publish.

Regular observations are being made on the solar constant at our stations on Table Mountain, California, and Mt. Montezuma, Chile. Owing to the complete expenditure of available funds, the observatory in Southwest Africa has been discontinued.

Washington, D. C., March 29, 1932

C. G. Abbot,
Secretary

Research in atmospheric electricity at the Stanford University

The observation-hut mentioned in last year's report has been completed and equipped so that at present continuous records of space-charge and potential gradient are being obtained at two different levels, one near the surface and the other at the top of a pole 16 meters above the surface. Wind-direction and wind-speed are also being recorded.

A very marked correlation has been observed between the wind-speed and consequent turbulence and the magnitude of the space-charge. This result was presented in a paper before the American Physical Society at Pasadena in June, 1931 (Abstract, Phys. Rev., v. 38, p. 587). Publication of the paper has been delayed until more records have been obtained.

Some work has been started on a comparison of the cage-method and the filter-method of measuring space-charge with a view to discovering the cause of the apparent lack of agreement between the values obtained by the two methods. It is hoped that this work can be continued soon.

P. D. Williams has completed his apparatus for studying the effects of nuclei and water-vapor on atmospheric ions and expects to get definite results in the near future.

E. A. Evans, after another summer of observation of thunder-storms in Colorado, is now carrying on experimental work in the Ryan high-voltage laboratory to verify if possible his theory of the mechanism of the lightning-stroke.

Joseph G. Brown,

Professor, Department of Physics
Stanford University, California, April 11, 1932

Geophysical work at the United States Bureau of Mines

Resistivity-surveys were made at the Legrande oil-pool in Hart County, Kentucky, to correlate, if possible, oil- and gas-structures with resistivity-measurements. The results of this work are presented in Technical Paper 521 (in press).

A careful study of magnetic anomalies measured by an Askania balance was made upon three representative iron ore-deposits. From the geophysical viewpoint they represent three different types of deposits. The results of this investigation are very interesting and are being published by the Bureau as Technical Paper 528 (in press).

Magnetic and electric observations upon veins and dike-like structures in the Sudbury District of Canada are described in Technical Paper 510.

A careful study is being made of seismic disturbances caused by blasting and similar mining operations. For this purpose precision-vibration calibration-apparatus has been designed and built, details of which are given in Technical Paper 518 (in press). A new style of seismograph recording-device especially adapted for this work has been developed and will be described in subsequent publications.

New simplified designs of geophysical apparatus are being constructed with a view to broadening the field of application of these instruments by greatly reducing the cost of manufacture. This, it is hoped, will make them more universally available than they are at present.

Careful studies were made of the adaptability of photoelectric cells for precision angular measurements. This was done with a view to shorten the time for making gravity-observations for prospecting purposes.

Scott Turner,
Director

Washington, D. C., March 25, 1932

Magnetic work of the United States Coast and Geodetic Survey

Magnetic surveys--In 1931 a test was made of the feasibility of making use of existing triangulation-stations as magnetic stations, particularly as repeat-stations for determination of secular change of the magnetic elements. The work was done near the 93rd meridian arc of triangulation from Minnesota to Arkansas. Former repeat-stations were reoccupied and new magnetic stations were established at triangulation-stations to be used as repeat-stations in the future.

It turned out that this particular piece of triangulation was not very well adapted to the purpose, as only about half of the stations visited were suitably located for magnetic observations and at only eight were distant objects visible which had been included in the angular measures. In most cases, however, a reference-mark had been set within a reasonable distance of the station and its azimuth determined with accuracy. Improved conditions for the work may be expected in future triangulation.

The magnetic stations in North Carolina reported not in good condition were visited and necessary observations were made to render them available for the use of local surveyors in making the compass-tests required by the laws of the State.

Declination-observations with compass-declinometer at triangulation-stations along the coasts of the continental part of the United States as well as of Alaska, Hawaii, and the Philippine Islands, made in connection with the hydrographic and topographic surveys, are furnishing more detailed information regarding the distribution of declination.

Observatories--The five magnetic observatories have continued to operate without serious interruption. At Cheltenham, Maryland, 14 Cour variation-instruments of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington intended for use during the Polar Year have been tested and standardized in cooperation with members of that Institution. Field instruments have been compared with the observatory standards. Messrs. J. W. Green and Earl Hanson of the Carnegie Institution of Washington stopped at San Juan, Porto Rico, for comparison of instruments in connection with their field work in the West Indies and South America. At Tucson, Arizona, the observations of atmospheric electricity and earth-currents have continued, in cooperation with the Carnegie Institution of Washington, the American Telephone and Telegraph Company, and the Mountain States Telephone and Telegraph Company. This Observatory has continued to furnish reports of magnetic character of days for the daily radio broadcast of cosmic data. A new set of variation-instruments has been installed at the Sitka Observatory, with temperature-compensation and reduced sensitivity ($H = 6.6\gamma$, $Z = 7.0\gamma$) and with the equivalent of two light sources, so that a reserve spot is provided for each variometer, thus insuring a complete record of even large disturbances. Special tests were made of the recorder in order to secure uniform rate of rotation of the drum. The H-variometer at the Honolulu Observatory has recently been compensated for temperature. With one or two exceptions, the intensity-variometers at all of the observatories are now compensated for temperature and the work of computing the results has been materially reduced in consequence.

Publications--As a result of a small increase in the office personnel and the use of the method of direct sealing of hourly values at the observatories, better progress is being made in the preparation for publication of the observatory results. Even though adequate funds for printing are not in sight, the completed manuscripts are available. The following publications have been issued during the past year:

Magnetic declination in the United States in 1930, serial No. 540.

Magnetic declination in North Carolina in 1930, serial No. 537.

Results of magnetic observations made by the U. S. Coast and Geodetic Survey in 1930, serial No. 544 (in press).

Results of observations made at the Cheltenham Magnetic Observatory in 1925 and 1926.

Results of observations made at the Honolulu Magnetic Observatory in 1925 and 1926.

Results of observations made at the Sitka Magnetic Observatory in 1925 and 1926 (in press).

The following are nearly ready for publication:

Results of observations made at the Tucson Magnetic Observatory in 1925 and 1926.

Results of observations made at the Cheltenham Magnetic Observatory in 1927 and 1928.

Results of observations made at the Honolulu Magnetic Observatory in 1927 and 1928.

Results of magnetic observations made by the U. S. Coast and Geodetic Survey in 1931.

Magnetic declination in South Carolina, Georgia, Alabama, Mississippi, and Louisiana in 1930.

The daily magnetic activity has been computed for 1930 and 1931 for each of the five magnetic observatories according to the formula recommended by the International Commission for Terrestrial Magnetism, $(HR_H + ZE_Z) 10^{-4}$.

Polar Year--Congress has authorized participation by the United States in the Jubilee Polar Year program, August 1932 to August 1933, the work to be done by the Coast and Geodetic Survey, and preparations have been advanced as rapidly as possible, so that prompt action can be taken when the necessary appropriation is made. The plans provide for the establishment of a temporary magnetic observatory at College, near Fairbanks, Alaska, equipped with three La Cour magnetographs. In cooperation with the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, provision will also be made for observations of atmospheric electricity, earth-currents, and Kennelly-Heaviside layer. The Alaska Agricultural College and School of Mines at College is already equipped for observations of the aurora and will cooperate in the other activities.

R. S. Patton,
Director

Washington, D. C., April 13, 1932

Work of United States Hydrographic Office in terrestrial magnetism and electricity

The work done by this Office in the general fields of terrestrial magnetism and electricity for a number of years has been proceeding with a view toward definitely locating storm-centers by means of static recorders.

Location of thunder-storms in the middle Atlantic states and the lower Lake region was accomplished by means of triangulation of static bearings taken during the months of July and August 1931. The Bureau of Aeronautics of the Navy Department operated two cathode-ray radiogoniometers, located during the experiments at Lakehurst and Cape May, New Jersey. The short base-line (about 80 statute miles) and local interference prevented satisfactory determination of the thunder-storm static centers in about half the cases observed. It was definitely shown that, due to the prevalence of static sources, it is essential that both stations make simultaneous observations on identical static flashes. This coordination was obtained by means of a leased telephone line.

The Hydrographic Office is planning another series of joint observations to be taken during May 1932. The direction-finders are located at the Naval Air Station, Lakehurst, New Jersey, and at the American Telephone and Telegraph Company's trans-Atlantic radio-telephone transmitting-station at Houlton, Maine. The Arlington time-

broadcasts will be utilized for synchronizing the two stations. Attempt will be made to track a storm across the United States by means of the bearings on its attendant atmospherics, or static.

The Naval Research Laboratory is constructing two cathode-ray static direction finders which are to be installed at Navy Radio Stations at Galveston, Texas, and Jupiter, Florida, during July 1932. These two instruments will be used to take cross bearings on West Indian hurricanes. When their reliability has been demonstrated, they will serve to augment ship reports now used in tracking and forecasting such tropical disturbances.

Further, consideration has also been given to the systemization of the international interchange of magnetic surveys and observations among the nations associated together as States-Members of the International Hydrographic Bureau at Monaco.

W. R. Gherardi, Rear Admiral, U. S. Navy,
Hydrographer

Washington, D. C., March 29, 1932

Work related to terrestrial magnetism and electricity of the
Naval Research Laboratory

H. B. Maris completed a list of magnetic storms for the years 1839 to 1930 and found that certain storms, about one-fourth of the total number, had a semi-annual period and not the period of solar rotation. He concluded that these storms may be of non-solar origin and due to the passage of the Earth across the planes of comet orbits; a complete analysis is under way. Dealing with the remaining three-fourths of the storms, he drew the average curve of the seasonal frequency and found that this was well accounted for by the ultraviolet-light theory of magnetic storms (see Phys. Rev., v. 39, 504, 1932).

R. Gunn continued the theoretical development of stellar electricity and magnetism. The titles of his published papers furnish a self-explanatory abstract of some of the results: On the electrical state of the Sun (Phys. Rev., v. 37, 983, 1931); On the axial rotation and spectra of stars (Phys. Rev., v. 37, 1573, 1931); Stability of the atmosphere of a rotating star (Phys. Rev., v. 38, 1052, 1931); On the evolution of a rotationally unstable star (Phys. Rev., v. 39, 130, 1932); On the origin of the solar system (Phys. Rev., v. 39, 311, 1932).

E. O. Hulburt assembled (see Terr. Mag., v. 36, 23, 1931) the auroral records of arctic and antarctic expeditions and substantiated Vegard's conclusion that the intense, moving, and strongly-colored auroral forms are more frequent in the evening than in the morning, the diffuse, weak, and quiet forms being more abundant in the morning. No other general conclusions could be drawn, and on the whole the data gave the impression that the diurnal course of an auroral display was different at the different stations as though it depended upon the meteorology of the upper atmosphere of the station. In a mathematical investigation (Phys. Rev., v. 38, 1876, 1931), he showed that the observed lower atmosphere of the Earth satisfied the conditions of radiative and convective equilibrium. He completed, as far as present data permit, the work on the ionization of the high atmosphere giving tables of the ionization over the Earth (Phys. Rev., v. 39, 977, 1932).

E. D. Almy, Commander, U.S.N.,
Director

Bellevue, D. C., April 7, 1932

United States Signal Corps

The Signal Corps Laboratories, Fort Monmouth, New Jersey, have been conducting a study of cosmic data received from the Science News Service in their relation to results obtained from Signal Corps radio transmission. Unfortunately, neither the cosmic data nor the transmission-results up to this time have been sufficiently complete to justify definite conclusions.

Their method of study is to represent all data graphically on the same sheet. Certain general trends are immediately apparent from these graphs. For example, we can

locate ourselves in the cycle of sunspot-activity and have noted that the decline in this activity parallels somewhat the decline in high-frequency transmission-results during the past year. These transmission results have grown consistently worse in spite of the fact that many improvements have been made in the transmitted signal. At the present time we appear to be passing through the worst period in the cycle for transmission at high frequencies. Certain other less marked relations are beginning to appear.

While the time required for broadcasting these cosmic data by radio places a limit on the amount of data that can be made available by that means, it is highly desirable that more detailed cosmic data be obtained and an effort will be made in the future to secure the additional data.

G. E. Kumpe, Colonel, Signal Corps,
Executive

Washington, D. C., April 4, 1932

P A P E R S

ON CALCULATIONS OF THE IONIZATION IN THE UPPER ATMOSPHERE

E. O. Hulburt

Experiments with radio waves, such as the measurements of the skip-distances, the time-intervals for short radio pulses to travel up to the high atmosphere and return, the polarization and the absorption of the waves, have shown that the regions of the high atmosphere above 100 km are heavily ionized, the maximum ionization being at about 200 km above sea-level. The radio waves indicated that during the daytime the density of the ions was about 10^7 at 100 km and increased with the height, and that the electronic density was around 10^3 at 100 km and increased with the height to about 3×10^5 at 200 km. At night the ionization appeared to separate into two separate banks, one at about 120 km with about 3×10^7 ions and one at a higher level with about 10^9 ions or 5×10^8 electrons. The diurnal variation of the magnetic field of the Earth is attributed to the diamagnetic effects of the ionization and indicated a total number of about 1.9×10^{16} ions in a 1-cm² vertical column up through the atmosphere which would amount to an ion density of 4.7×10^9 in the levels from 150 to 150 km at noon at the equator; the ionization at night was about 1/8 of that during the day. Further than this the exact distribution of the ions and electrons with height and the manner in which the distribution changes during the day and the night can not be derived from the data of radio and terrestrial magnetism which are available at the present time.

On the theoretical side it was of interest to discover if possible what caused the ionization, and briefly it may be said that the main features of the ionization may be accounted for on the assumption that the ionization is caused by the ultraviolet light of the Sun. To arrive at this conclusion it was necessary to work out the correct meteorology of the high atmosphere and to take careful account of the electric and magnetic influences which are present there.

The early calculations assumed a static atmosphere in the high levels, cold all day and all night with no winds or motion or diffusion of the gases. An ionization was assumed, caused by the ultraviolet light of the Sun, in agreement with the daytime radio facts. Upon calculating the degradation of the ionization at night from recombination of the ions and electrons it was found that the ionization decreased but slightly during the night. The calculated radio wave skip-distances only lengthened about 10 per cent at night, whereas they were observed to lengthen by about a factor of two. Such a pronounced discrepancy indicated that something was radically wrong. It turned out that the conception of a cold quiet high atmosphere was untenable. Winds exist there, as shown by the drift and movement of meteor-trains, and calculation showed that the levels about 50 km are made hot by the Sun during the day and are cooled by their radiation at night. So that the atmosphere is not static but the gases are continually stirred by winds and any calculations of the ionization must take the diffusion of the ions into account.

When this was done better agreement was secured with the night skip-distances, except that they came out a little too great, for the calculated ionization decreased a little too fast at night. Also at this stage the theory gave no indication of a double layer of ionization at night, although to be fair the two banks had not been discovered at that time.

The electric, magnetic, and gravitational forces acting on the ions were considered in addition to the effects of diffusion and the theory began to assume the more finished appearance which it now has. It was recognized that the long free-path ions and electrons under the influence of the gravitational and magnetic fields of the Earth drift in a direction perpendicular to these two vectors, the positive ions going east and the negative ions and electrons west. The displacement of charge gives rise to a horizontal electric field which is westward over the day hemisphere and eastward over the night hemisphere. The electric field combined with the Earth's magnetic field causes the long free-path ions of both signs and electrons to fall slowly during the day and to rise at night. At night the long free-path ions ascend and the underlying short free-path ions remain where they are being unaffected by the field, and as a result the ionization separates into two banks. Almost exact agreement was found with the night skip-distances. The diamagnetism of the ionization accounted well for the diurnal changes in the magnetism of the Earth.

At the present time there appears to be no marked discrepancies between theory and experiment. There remain, however, many things which are imperfectly known, such as the exact distribution with height of the ions, the electrons, the ozone, etc. It may be hoped that further experiments with radio waves and investigations of terrestrial magnetism as well as laboratory measurements of the photo-ionization of gases will gradually yield more complete information about the physical state of the high atmosphere.

Naval Research Laboratory,
Bellevue, Anacostia, D. C.

THE GEOPHYSICAL SIGNIFICANCE OF RADIO MEASUREMENTS OF THE IONIZED LAYER

M. A. Tuve

I have been asked to summarize the extent of our present knowledge of the relations which are known or thought to exist between radio measurements of the ionized layer and other geophysical problems, and to refresh the minds of those of you who may have forgotten some of the details of such measurements and their interpretation.

Geophysical data may be classified in two groups, namely, data from physical analysis and data from statistical analysis. Physical analysis can establish the existence of a geophysical condition or entity. Statistical analysis can establish relations between geophysical variables. I shall divide this talk similarly. First let me remind you very briefly of the basis of the physical analysis in the problem under consideration.

In general it is observed that in addition to the ground-wave there is a sky-wave. This is interpreted in terms of an ionized region in the upper atmosphere. To date five methods have been developed for measurements on this ionized region, chiefly measurements of its equivalent height. The results by the different methods are as concordant as would be expected.

(1) When the transmission-frequency is changed continuously through a small increment, interference maxima and minima are observed at receiver due to the ground- and sky-waves.

(2) Echoes are observed having retardation corresponding to reflections from heights of 100 to 400 km and higher, when pulses of short duration are sent out by transmitter at S (Fig. 1).

(3) The angle of incidence of the waves at the ionized layer (or rather the angle of reflection) is observed by combination of loop and antenna observations at receiver R (Fig. 1).

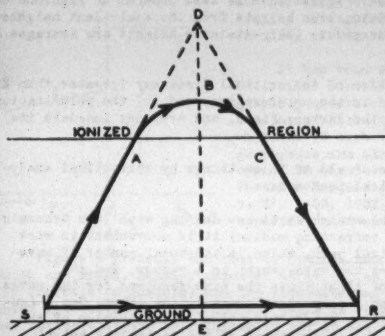


Fig. 1--Radio wave-paths

for the equivalent height $S D R$ (Fig. 1), whereas the true path followed by the waves is, for example, $S B R$ (Fig. 1), that is, the waves may be refracted by a gradual increase in ionization with height beyond A, instead of traveling with the velocity of light to the point D and being reflected there. The time of travel is the same for either path. The important point is that the true heights to which the waves travel must be obtained indirectly from the equivalent heights which are actually measured. This leads to an important difficulty, which will be mentioned presently.

The physical analysis of the phenomenon can proceed much further before it is required that statistical analysis must enter as the primary source of information. For example, the ionized region appears to be stratified. In general very long waves are returned from heights of 60 to 80 km. Intermediate frequencies up to 2,500 or 3,000 kc are returned from a height of 90 to 110 km. The ionization at this level (called by Appleton the E-region) is insufficient to return higher frequencies except sporadically, but such waves are returned during the daytime from an equivalent height of about 230 km. This higher region Appleton has named the F-region. Its upward extent (measured by higher and higher frequencies) will be indicated to you by the Bureau of Standards' observations which Mr. Berkner will report.

The diurnal variation for any one day or for a group of days can be observed. Whether this is a typical condition or not is a statistical question. [Records were shown of the diurnal variation observed by the echo-method at the Department of Terrestrial Magnetism, Washington, D. C., October 7, 1928, and similar observations by Appleton and Builder, London, July 15, 1931. See original papers already published.]

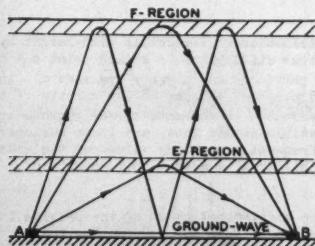


Fig. 2--Diagram various paths by which pulse may arrive at receiving station

(4) Skip-distance phenomena at high frequencies have been used to obtain an average height of the layer in terms of critical angles for reflection (refraction). Incidentally there appears to be a growing basis for wondering whether the interpretation of skip-distance phenomena has been correct, or perhaps rather complete.

(5) A moving transmitter, for example in an airplane, gives rise to interference-fringes between ground- and sky-waves which move over the receiver.

Such results as are obtained by these methods and the others prove the existence of an ionized region.

An important point in connection with all of these measurements is that the result of an observation is a value

Just what can the radio analysis of the ionized region ultimately tell us? As far as we can see at present, the following things we can measure or may hope to learn:

- (1) The maximum ionization (equivalent electrons per cc) in the E-region by the frequencies at which the E-reflections disappear.
- (2) The maximum ionization in the whole layer, at least at certain times (this may be masked by absorption) by frequencies at which no energy is returned.

(3) The curve for ionization against height. This is less hopeful of rigorous deduction because of difficulties in obtaining true heights from the equivalent heights or virtual heights which all four methods give. (Skip-distance heights are averages at best.)

(4) Incidental data: (a) The position of the critical frequency (greater than 214 meters) gives the Earth's magnetic field in the upper region, and (b) the polarization of down-coming waves is related also to the Earth's field, and even may indicate its changes (if sudden enough).

(5) Finally the variation with time of all of these things by statistical analysis may show relations to other geophysical phenomena.

In the treatment of an optical problem such as we are dealing with (the transmission of electromagnetic waves through a refracting medium) it is convenient to work with two kinds of path, namely, the optical path, which is the total number of wavecrests from transmitter to receiver times the wave-length in a vacuum, and the equivalent path, which is the velocity of light times the time required for the waves to travel over the actual path. Appleton's very clear presentation (Phys. Soc., London, v. 42, 321, 1930) will be followed in a brief discussion of the problem of the determination of the actual height from the observations of the equivalent height.

The optical path $P = n\lambda = \int \mu ds$, where μ is the refractive index. The equivalent path $P' = c \int \frac{ds}{u}$, where u is the group-velocity. For short waves (at some distance from the critical frequency near 214 meters due to the Earth's magnetic field) this reduces to $P' = \int \frac{ds}{\mu}$. The optical path P and the equivalent path P' are related by $P' = P + f \frac{dP}{df}$. From this it follows directly that $P = \frac{1}{f} \int_0^f P' df$. That is, the area under the (P', f) curve from zero to the frequency f gives the optical path P for the frequency f . Now since the refractive index of the ionized region is less than unity, the actual path must be greater than P and less than P' . Thus if P and P' are both determined, limits are set for the actual path, or the "true height." It should be noted that changes in the distribution of ionization with height may change both P and P' without altering the actual height to which the waves travel.

Recalling the fact that as the frequency of the waves is increased to about 3,000 kilocycles they penetrate the lower E-region and are sent back from a region (the F-region) with retardations corresponding to an equivalent height of 230 km or more, there will consequently be a discontinuity in P (a sudden jump in the number of wavecrests) at the frequency f_1 (see Fig. 3) at which the waves just penetrate the E-region. This will give rise to indeterminately large values of

$P' = P + f \frac{dP}{df}$. Hence $P = \frac{1}{f} \int_0^f P' df$ cannot be rigorously evaluated for a frequency f_2 , that is, for waves returned from the F-region.

The determination of the curve for the distribution of ionization with height by these radio methods is thus attended with a serious difficulty. I should point out that $\mu^2 = 1 - N e^2 r^2 / \lambda m$, where N = the number of free particles of charge e and mass m . At the maximum height on the actual path $\mu = 0$, and hence at this point the density of the charged particles is given by $N = (\lambda m / e^2) r^2$. By reason of the mass term-electrons are 1,800 times more effective than the lightest possible atomic ions, and it is customary to discuss an "equivalent electronic density" (frequently reaching values of the order of 10^5 electrons/cc) without excluding the possibility of a much larger density of heavier ions.

In turning from the physical analysis to the statistical phase of the problem I want to call your attention very briefly to some special methods for testing the validity of statistical deductions. Apparently most of us have had for years a feeling of distinct dissatisfaction with the vagaries of statistical phenomena and their interpretations, which change with the ease of chameleons, and we have hungered vaguely

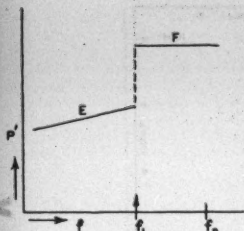


Fig. 3

and perhaps a little lazily for better criteria for the reality of statistical correlations--criteria for the validity of statistical conclusions.

It has been a delight this past year to learn from Dr. Julius Bartels some of the special tests he uses for settling questions of exactly this kind, and to learn something of the background of this mathematical technique which is of such exceedingly fundamental importance to geophysics and almost no less important in every other branch of physics. What follows presents a small part of what Dr. Bartels gives in a recent paper (see Terr. Mag., v. 37, 1-55, 1932) which indicates admirably the practical application of such tests.

Figure 4 presents the records for the two best correlated geophysical variables which are known, namely, magnetic activity, as measured by the inter-diurnal variability (Bartels' u -measure) and the international relative sunspot-numbers (R). There are large fluctuations in the monthly means as compared with the annual means. In particular notice that the correlation is not at all obvious in the curves (and can be shown from the data itself to be actually very low or zero) for many periods which are shorter than a whole cycle. This emphasizes an exceedingly important point, namely, it is unsafe to conclude that correlations are present or absent unless data for more than one period or cycle are available. Furthermore, the data themselves must tell us what the lengths of the cycles are.

These two geophysical variables show an exceedingly high correlation: For the 59 annual means 1872-1930, the correlation-coefficient is +0.884; for the 708 monthly means 1872-1930, the correlation-coefficient is +0.654. However, note that for years near the ends of certain sunspot maxima the correlation is obliterated. Thus for the 36 monthly means 1918-1920 the correlation-coefficient is +0.06, and for the 36 monthly

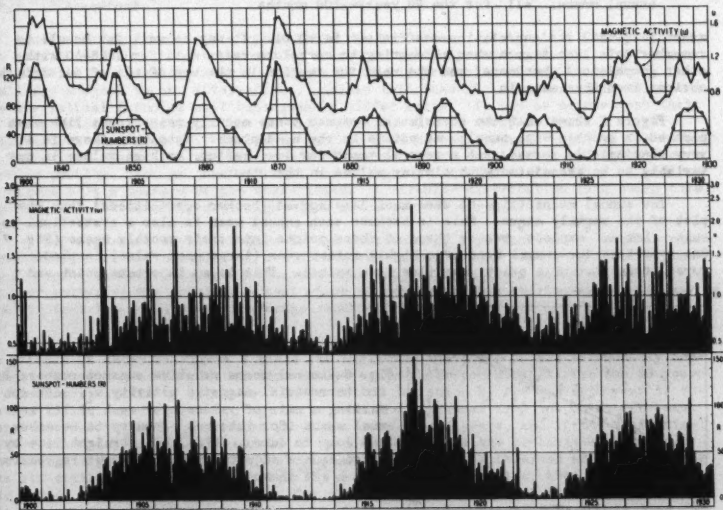


Fig. 4--Annual and monthly means of magnetic activity and sunspot-numbers, 1900-30

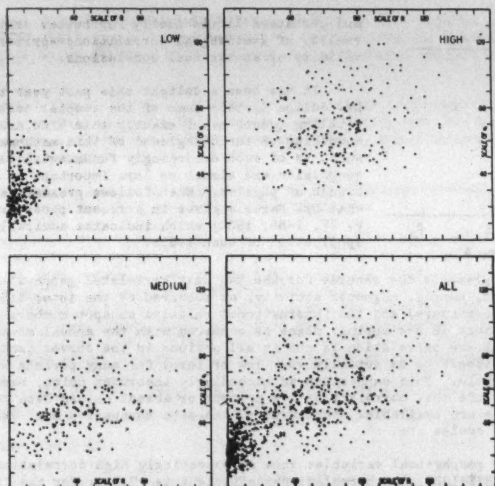


Fig. 5--Monthly means relative sunspot-numbers R and terrestrial magnetic activity u_1 , 1872-1930: High for 20 years with annual means $u_1 \geq 68$; low for 20 years with annual means $u_1 \leq 42$; medium for 19 years with intermediate annual means; all for the 59 years--708 months

means 1928-1930 the correlation-coefficient is +0.01. It may be well for us all to remember this last figure when attempting to correlate radio data for 1928-30 with other geophysical phenomena, and the need for caution in the use of all of our data is obvious from this example.

Figure 5 shows what the correlation between these monthly means looks like when plotted in another way, namely, as points in the u_1 - R plane. Note that there is a very considerable spread, but a general trend for low, medium, or high values in one variable to be associated with similar values in the other.

The annual means (Fig. 6) show much less spread (better correlations) than the plot of the monthly means. This is because each annual mean is also a statistical result. Let us 'explode' two or three of these points into their monthly means (Fig. 7). One sees that the annual mean of a highly active year (large mean value) 'explodes' much worse than that of a quiet year (low mean value). This is an important point and

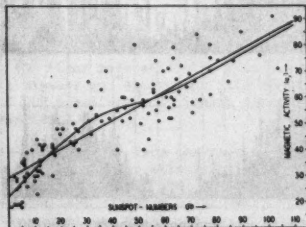


Fig. 6--Annual means relative sunspot-numbers R and terrestrial-magnetic activity u_1 , each dot marking a pair of values, for each of 117 annual means (for interval January to December and July to June), 1872-1930; straight line by least-square adjustment and a curved regression-line L are shown

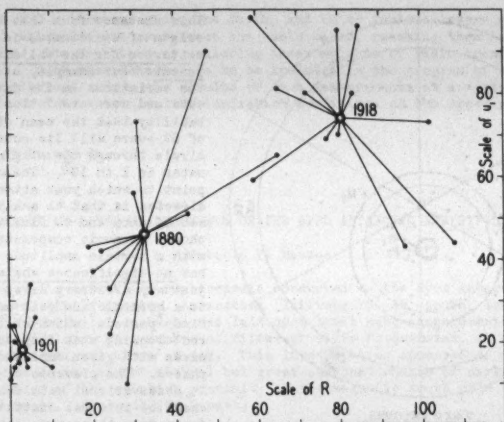


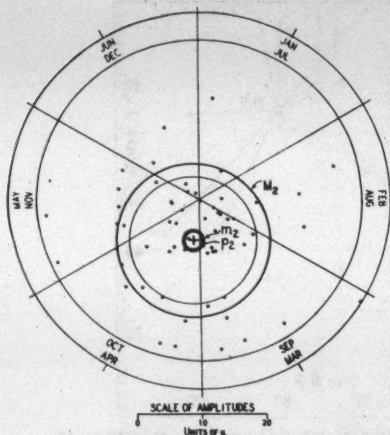
Fig. 7--Relative sunspot-numbers R and terrestrial-magnetic activity u_1 in year of high activity (1880), medium activity (1890), and low activity (1901), demonstrating relations between correlation-coefficients for annual means and monthly means

characterizes this particular statistical problem. Every statistical problem must be individually treated. This is an example of a statistical variable which shows a large "after-effect."

Another example of such a variable is the barometer. If the last hourly reading has been 30.0 inches, the next reading is not an entirely random matter. In fact, that it will be somewhere near 30.0 again is highly probable. Brownian movement is similarly subject to an after-effect, and in this case it is in three dimensions. The statistical formulae will consequently differ again. It may be pointed out that by the greater smoothness of the monthly means for R this variable shows a larger after-effect than does u_1 . Reference must be made to the original paper in the Journal of Terrestrial Magnetism and Atmospheric Electricity for details concerning this particular problem. Let me just say that the ellipticity of the distribution as plotted in Figure 5 is a measure of the correlation. A circular distribution in a plane this way means no correlation, a straight line means perfect correlation.

Brief reference should be made to two particularly important types of tests which Dr. Bartels uses and examples of which he gives in his paper. One is a test for the reality of a harmonic component obtained when subjecting a given set of data to a Fourier analysis; the other is a test which is not restricted to sine-waves, and may be used to test the reality of an average recurrent variation.

For harmonic components Dr. Bartels constructs what he calls a "harmonic dial." An example is shown in Figure 8 where the amplitude and phase of the six-monthly component for each year is plotted separately (as in polar coordinates) for the 59 years of the magnetic data of Figure 4. The standard deviation M_2 for a single year is obtained as indicated, where $d_1, d_2, \dots$, are the distances from the points for each separate year to that point which gives the mean of all years, and if the statistical distribution is "normal" the circle of radius $0.833 M_2$ is the probable-error circle for a single year. That is, if a single additional year is observed and analyzed for its six-monthly component, it is equally probable that its point, when plotted, will lie inside or outside this circle. Now since the distribution of the points is statistical, the standard deviation for the whole group of N years is less than that for a single year by $1/\sqrt{N}$, that is, $m_2 = M_2/\sqrt{59}$. The circle p_2 , whose radius is $0.833 m_2$ predicts the probable position of the mean component for another group of 59 years.



Harmonic dial for the 6-monthly waves in the magnetic activity u_1 for each of 59 years, 1872 to 1930.

$$M_2 = \sqrt{\frac{d_1^2 + d_2^2 + \dots + d_{59}^2}{59}} \quad m_2 = \frac{M_2}{\sqrt{59}}$$

$$P_2 = 0.833 m_2$$

Fig. 8

essentially in determining whether the variations decrease with $\sqrt{N}$ as the number of observations increase. Variations which do not decrease in this way are due to causes other than statistical fluctuations. Thus given data for N years of 12 monthly means to test for systematic annual variation: (1) Form for each year the departures of the 12 monthly means from the mean of that year. The standard deviation of these departures is σ . Then for a number of years N , according to the law of propagation of accidental errors, we should expect a standard deviation $\sigma/\sqrt{N}$. (2) Compute σ_m , the standard deviation for the 12 $\cdot$ N monthly means, using the mean of all years (instead of the means for separate years). The ratio of σ_m to $\sigma/\sqrt{N}$ is an index of the reality of the suspected annual variation. If this ratio is considerably greater than unity (say 1.5 or 2.0) it constitutes valid evidence that the annual variation under consideration is real.

If I have indicated the necessity for critical treatment of statistical data which certainly confronts those of us interested in correlations of radio phenomena with other geophysical data, I have succeeded in the chief aim of this paper.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

RADIO EXPLORATION OF IONIZATION OF THE UPPER ATMOSPHERE

J. H. Dellinger

(Abstract)

Radio-transmission experiments offer an increasingly powerful tool for the determination of the electrical condition of the upper atmosphere. There is an ionized

This distance from this circle to the origin of coordinates is a real criterion for the validity of the component. For example, assuming that the variations in the data already obtained were statistical, the probability that the mean of a new group of 59 years will lie outside of a circle through the origin of coordinates is 1 in 10^7 . The outstanding point to which your attention is directed is that to analyze a given set of data and to find that a chosen harmonic component is present with a certain amplitude and phase has no significance whatever. Subject any arbitrary array of numbers to a harmonic analysis and you will find periods which will be very real looking when they come out as waves with given amplitudes and phases. The presence of real periods in observational data can only be shown by internal statistical evidence from these same data. Thus, this harmonic-dial test obtains a quantitative criterion for the reality of a period found in the mean of the 59 years from the statistical fluctuation of the same period in the data for each of the 59 years.

Brief reference only will be made to the other type of test indicated by Dr. Bartels and which is not restricted to sine-waves. It consists

layer at about 100 kilometers above the Earth, and other ionized layers are found at higher levels, which reflect or refract the radio waves, reaching them back to the Earth's surface. The technique of measuring these heights by radio transmission is well developed. Such measurements are to be included in the program of some of the Polar-Year expeditions. From the results of such measurements at a variety of radio frequencies, much information on the ionization-conditions of the upper atmosphere is being secured.

U. S. Bureau of Standards,
Washington, D. C.

KENNELLY-HEAVISIDE-LAYER MEASUREMENTS ON THE BYRD ANTARCTIC EXPEDITION, 1929-30

Malcolm P. Hanson

Among the radio scientific measurements conducted on the Byrd Antarctic Expedition at its base, Little America, Antarctica (latitude $78^{\circ} 35'$ south, longitude $163^{\circ} 48'$ west), particular emphasis was laid upon local echo-measurements of the Kennelly-Heaviside layer at a number of different radio frequencies, at several seasons, and over varying times of day. This investigation appeared of especial importance because of the slight diurnal but great seasonal change of darkness and sunlight, and because of the relative proximity of the magnetic south pole (approximate latitude 72.4° south, longitude 154.0° east).

The experimental method employed consisted in sending out from the high-frequency radio transmitter at Little America, brief impulses of approximately 0.0005-second duration, spaced at measured rates of approximately 160 per second by means of a synchronous commutator. In the first measurement series supplementary observations were taken with impulse frequencies around 1/6 second to discern against overlap and study more delayed echoes; subsequently a satisfactory single compromise method was adopted in which the rapid impulse train was briefly interrupted approximately every 1/10 second by an automatic vibrator.

Oscillograms of the reception of these signals with their echoes were taken at distances ranging from five to fifteen km from the transmitter, with portable equipment transported by dog-sled, and set up in a tent on the ice. A simple portable receiver comprising regenerative detector and two-stage audio-frequency amplifier was used, followed by a Westinghouse "Osico" portable oscillograph originally of the single-element type, but modified by addition of a second element for the timing-wave and other alterations rendering it suitable under somewhat difficult conditions of operation. Thus the original heavy mineral-oil damping-fluid was replaced by a kerosene-gasoline mixture to prevent freezing at temperatures sometimes exceeding -50° C. A simple source of timing frequency was provided by means of a magnetophone, consisting of a telephone receiver functioning as electrical generator when actuated by a calibrated musical pitch pipe attached to it; a heat-insulating mouth-piece enabled the observer to carry this unit between his lips, leaving his hands free for adjustment of apparatus and manual rotation of the film-drum. To prevent freezing of the reed, it was found necessary to arrange the pipe for inhaling rather than blowing, and to support it atop a lantern when not actually in use. In cold weather it was also found essential to pre-heat all dry batteries and to maintain them well above -30° C to restore their activity. Thin but dense silk-gloves were found invaluable in enabling manipulation of the equipment at low temperatures.

The base-station at Little America, when advised by the detached station's portable transmitter, would commence its schedule, transmitting the special impulses for ten or fifteen minutes on each of four to six different frequencies ranging from 86 to 30 meters in wave-length. These schedules were repeated at usually four- to six-hour intervals, over a total period as long as conditions permitted, at least 24 hours.

After several unsuccessful efforts and repeated trials in temperatures from -35° to -65° , suitable modifications to apparatus and technique were developed, resulting in a successful winter-night field trip with a 24-hour series of measurements on July 20, 1929. A second 24-hour series was taken during the early spring, August 29-30,

1929, with the Sun above the horizon for less than an hour at noon. A third and final group of measurements was obtained from January 16-19, 1930, during continuous sunlight and favorable midsummer weather-conditions which made possible the extension of schedules throughout a 68-hour period.

Altogether, about 900 oscillographic traces were obtained, each covering a time-interval from one-quarter to one-half second. These records have been measured at the Naval Research Laboratory and will be analyzed for correlation with other available data. While constituting only fragmentary samples of somewhat limited experimental accuracy and resolution, they are in sufficiently consistent agreement to be considered representative of general conditions of the diurnal and seasonal variations encountered in the region of Little America. It is hoped that more continuous and accurate measurements of the reflecting-layer in the Arctic as well as Antarctic regions will be added in the early future, with which the data herewith discussed may be compared. Likewise, despite its incomplete state of analysis, it is thought that since it covers what is believed to be the first and to date perhaps still the only series of

such measurements in the polar regions, the present discussion may be of some help in the extensive investigation planned along this line for the International Polar Year.

Figure 1 is a representative portion of one of the typical oscillograms obtained, slightly reduced in scale. It shows the ground-wave or direct-ray impulses of approximately constant amplitude and wave-form, each followed by the "sky-wave" or reflected-ray echo, of gradually varying amplitude and apparent change in wave-form due to overlapping split-reflections, etc. By use of suitable antenna-systems for transmission and reception, it was possible even at a distance of 5 km to discern against the direct ray so that the echo usually predominated; in fact, the distance of 15 km at first chosen, despite the flat intervening snow-surface, attenuated the direct ray to such an extent that only a strong sky-wave was recorded on some traces.

The complicated and often rapidly varying reflection-pattern encountered on a large portion of the records rendered identification and measurement of individual successive peaks difficult until facilitated by development of a special harp-like multiple parallel-ruler consisting of an adjustable celluloid parallelogram traversed vertically by a number of stretched threads of adjustable but equidistant spacing. The order of resolution and photographic detail of most of the records and the order of precision of the timing-methods employed are such as to limit the probable experimental error to about 10 per cent. Representation of the predominant reflections of the frequency-time runs by a single representative value was sometimes a difficult matter of judgment in cases where rapid variations and diversification in



Fig. 1.—Specimen of reflecting-layer oscillogram obtained near Little America, Antarctica, 1929

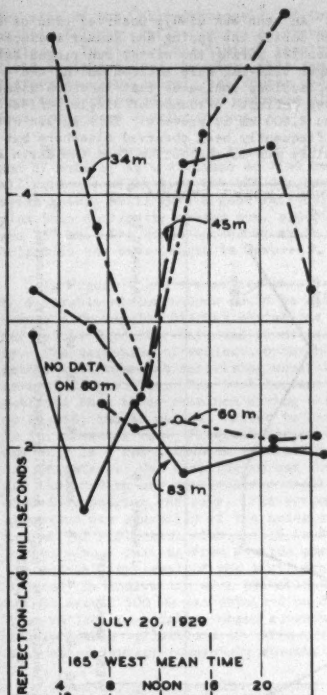


Fig. 2

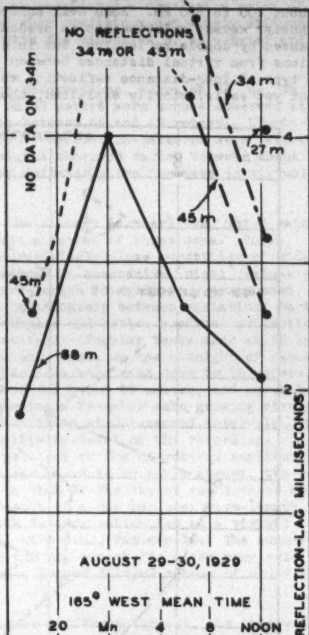


Fig. 3

echo-time were found, as a rule, coupled with rapid changes and interchanges of echo-amplitudes. As far as the limited sampling permits these variations are being further studied and compared with those observed in other regions. Of particular interest and complexity, in this respect, are the winter-night series of observations.

In interpreting the observations herewith discussed, the position of the Sun should be borne in mind. Thus, declination tables show that during the July (winter) run the Sun's position ranged from approximately 9° to 32° below the horizon, causing a region of darkness extending at local midnight about 1,000 km, at noon only about 82 km above the Earth's surface. While even in midwinter, in the latitude of Little America, sunlight daily approaches to within 140 km of the Earth, these low tangent-rays are attenuated by such a long passage through dense atmosphere as to have negligible ionizing-value. During the August observations (spring), the Sun's altitude ranged from about 2° above to 22° below the horizon, while for the January (summer) observations the altitudes range from 10° to 34° above the horizon.

The winter observations are summarized in Figure 2. Runs were alternated on 34, 45, 60, and 83 meters. The first set of 60-meter observations was lost due to photographic failure. The 34- and 45-meter curves show pronounced diurnal variation, which appears absent in the 60- and 83-meter measurements. Of especial interest is the height concentration obtained for all frequencies during the 10 to 11 a.m. tests; of all measurements taken, this is the only notable exception to the pronounced increase

in echo time-lag with decreasing wave-length. An echo was always observed even on 34 meters, in contrast to the out-off experienced during the spring and summer measurements. Observed virtual heights on all frequencies during the winter run ranged from about 200 to 800 km. Some weak echoes of longer time-lag were noticed on the two shorter waves; relationship to predominant reflections indicates that they are usually caused by double reflection, but in a few cases definite evidence of single reflections from virtual distances between 1,200 and 2,500 km is present. This agrees with a type of long-distance reflection which has frequently been observed elsewhere but is not yet satisfactorily explained, though possibly due to reflection from the Earth at

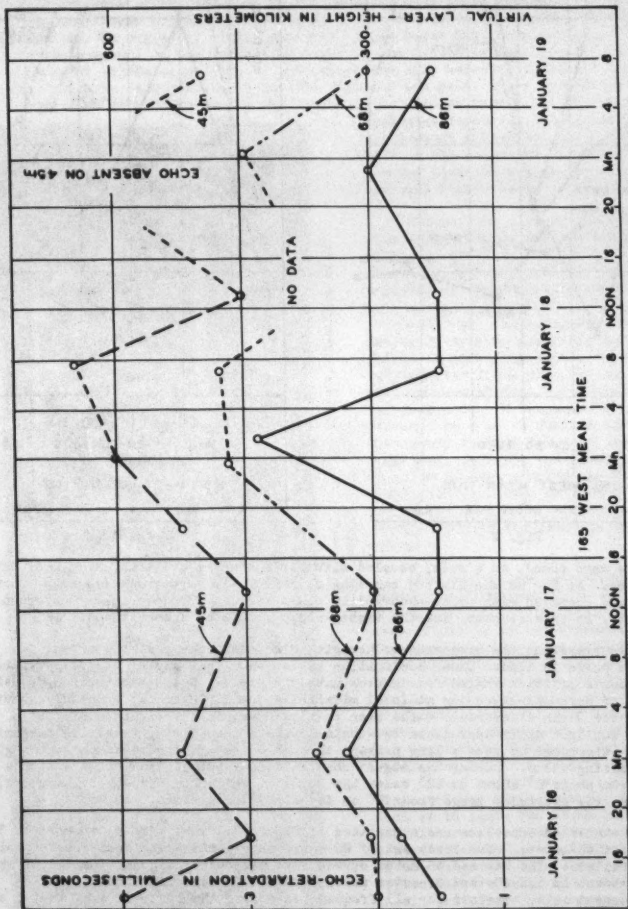


Fig. 4--Summary mean values predominant reflections for heights Kennedy-Heaviside layer measured at Little America, Antarctica, January 16-19, 1950

the edge of the "skip-distance." No indication is found, even on 83 meters, of so-called E-layer reflections from around 100 km which are frequently observed in other regions. In view of the limited sensitivity and oscillographic resolution of the field equipment used, however, this can not yet be considered a conclusive point of difference. In general, the winter observations show conditions not widely different from those observed in more moderate climates, with the exception of more brief and less pronounced daytime values.

Figure 3 represents a summary of the spring observations, taken on 68, 45, 34, and 27 meters, at a distance of five km. Only on 68 meters were echoes observed at all periods, night-time cut-off apparently lying between 68 and 45 meters. Twenty-seven meters still gave a good reflection at noon. Reflection-patterns were less complex than during the winter run, and virtual heights observed varied between about 225 and 750 km. The echoes observed again show very definitely the increase in virtual height as the wave-length is lowered.

In Figure 4 are summarized the results of the January (summer) run, which owing to favorable circumstances could be extended over a period of three days. These curves show regular diurnal variations with a surprisingly close repetition of mid-day values day after day, and pronounced differences in successive night values only. The variation of reflection-height with wave-length is again very pronounced, together with somewhat surprising consistency in relationship between variations on the several frequencies. The oscillograms showed simpler and better confined reflection-patterns than those obtained during the other seasons. Regular tests made at 12 km, on 86, 68, and 45 meters, failed to show echoes only once, on the midnight of January 16 for 45-meter run. Frequent additional observations were made down to 18 meters, but only in a few instances were reflections observed below 40 meters, and never below 35 meters. One oscillogram was obtained showing a 36-meter echo growing strong and then fading out completely several successive times at 0.1-second intervals, and then disappearing entirely. The estimated sensitivity-level of the recording-apparatus was generally of the order of a few per cent of the direct-ray amplitude. Cut-off of reflection with change in frequency was found to be quite abrupt, the recorded echoes falling from a value comparable to that of the direct ray down to below the sensitivity-level of the instrument as a result of a one per cent wave-length decrease. An indication of a probable though weak E-layer reflection at a virtual height around 100 km was obtained on 86 meters, at 6 p.m., January 16. The summer-time reflection-heights ranged between 200 and 675 km, except for a few very evidently double reflections of twice the time-lag. Longer delayed echoes of other than this nature appear completely absent.

Summarizing the results obtained at the three different seasons, the observed echo-times have shown virtual reflection-heights ranging between 200 and 800 km. On the 83- to 86-meter waves, reflection-heights ranged from 200 to 450 km; the 68- and 60-meter observations gave virtual heights generally between 250 and 450 km, with some extensions up to 650 km. The 45-meter reflection-zones corresponded to virtual heights mostly between 375 and 650 km, while the 34-meter echoes--obtained during winter and spring only--ranged from 400 to 800 km. Because of continuously variable virtual heights up to about 800 km and a sudden cessation above this value, it is concluded that this value represents the physical limit of simple reflections covered by these observations.

It is hoped that in the near future it will be possible to complete correlation of the observations described in this paper with concurrent magnetic and other conditions, and with similar more complete data obtained in other regions. It is of course gratifying to note the present-day high state of technical development of apparatus enabling continuous records of the reflecting-layer to be obtained with great accuracy, and the plans to obtain such records in many new regions. In the opinion of the writer, future measurements in cold climates should be made with apparatus permanently set up in heated buildings, but a wide field still exists for field observations in many regions where only portable equipment is practical. Development of portable transmitting, receiving, and recording equipment, light in weight and compact, yet rugged, appears highly desirable to supplement the more elaborate measurements made at fixed stations; a further refinement by which the impulse transmitting- and receiving-apparatus may be placed alongside of each other, and controlled by only one observer,

would appear most valuable for detached field measurements. Direct visual observation should of course be provided for, in addition to provision for photographic recording.

The observations herein described were made by the author while detailed by the Navy Department as radio engineer to the Byrd Antarctic Expedition. Preparations for this work and subsequent analysis were made at the Naval Research Laboratory, Bellevue, D. C., under Drs. Taylor and Hulburt. Dr. G. W. Kenrick, Lieut., U.S.N.R., collaborated in the analysis during a period of active duty.

U. S. Naval Research Laboratory,
Bellevue, Anacostia, D. C.

SOME COMMON PERIODICITIES IN RADIO TRANSMISSION-PHENOMENA

G. W. Kenrick and G. W. Pickard

It has been recognized for several years that radio transmission under conditions such as largely involve the Kennelly-Heaviside layer is distinctly (and often highly) correlated with solar activity and terrestrial magnetism. As the active areas on the Sun (which may or may not be accompanied by sunspots) are successively presented earthward, the solar rotation-period of 27.5 days is often definitely impressed upon radio transmission. More recently Stetson has presented certain evidence of a lunar effect upon radio reception, in the form of a correlation between the Moon's altitude above or below the horizon and the night field from WBBM.

It is the purpose of this paper to examine all available data for further evidence of a lunar effect upon radio transmission. To this end, four rather diverse series of reception-measurements have been selected. The first and longest series consists of Austin's 10 a.m. measurements of Nauen's (POZ, AGS, DFW) field at Washington, at a frequency of 31.1 kc and over the period 1922-31. Systematic measurements of this station actually go back to 1915, but early in 1922 Austin introduced his telephone-comparator method of measuring the signal, which had been previously estimated by audibility-meter, and because of the greater accuracy of the last ten years of this series they alone have been used.

The second series is the mean field from 9-10 p.m., measured at Boston, of station WBBM of Chicago, operating at 770 kc. This series extends over an interval of six years, from 1926 to 1931, and for the purpose of eliminating seasonal and other long-period effects, each night's field has been divided by a 27-day mean centering on that night.

The third series is that taken by Brown at Pasadena, California, from stations KWFI and KPO of San Francisco, now operating at 680 kc, of the mean field from 9-10 p.m., Pacific standard time. This series started in the summer of 1927, and has been used herein to the end of January, 1932, an interval of four and one-half years. As with WBBM, the field has been reduced to a ratio with the 27-day mean.

The fourth series is the ratio of the mean-day to mean-night field as measured at Boston from station WCI at Tuckerton, New Jersey, operating at 18.4 kc. The characteristic changes of this ratio with magnetic disturbance have already been described. This is the shortest of the four series, extending only from June, 1928, to December, 1931, and by itself, this series is probably too short to definitely establish therein the existence of a lunar period. However, its close agreement with the others renders it significant.

Several methods of harmonic analysis suggest themselves for this investigation. These include the classical methods of Balfour Stewart and Schuster and the more recent modifications devised by Clayton (World weather, 1923, Appendix C and p. 298). It is beyond the scope of this paper to enter into a detailed discussion of these methods and only a few of the salient results will be mentioned here.

It is perhaps sufficient to note that Clayton's methods are well adapted to provide a rather high degree of resolution between several nearly equal periods. Using his method, one investigates the precession of phase between the periodicities in the

series under investigation with respect to a trial period of nearly equal length. The available data is divided into a number of intervals equal in length to the trial period and the amplitudes of the frequency under investigation is then derived for each successive period using sine and cosine products and a method closely analogous to that used in ordinary Fourier series analysis to compute amplitudes. If several prominent periods near but not exactly equal to the trial period are present in the data, the amplitude of the Fourier coefficients by successive trial-period intervals will vary at a complex beat-frequency and the phase of the periods of maximum amplitude will precess regularly at different rates for the different periods present. When applied to the available POZ-data, this leads to a plot of the form shown in Figure 3. The amplitudes for the successive 30-day intervals in the plot chosen for Figure 3 have coefficients for successive 30-day intervals as shown in the lower plot, called the "ampligram." The precession of phase for these major amplitudes is investigated in the upper plot called the "phasogram." The rate of precession of the phases of the 30-day fundamental component for the periods corresponding to maxima in the ampligram should lay on straight lines if marked and persistent periodicities exist, and the slope of these phase-angle lines together with the known length of the trial period, determines the true period. The amplitudes of these periods may be investigated subsequently by dividing the data into the intervals indicated for the true periods and then computing the amplitudes of the coefficients by Fourier series methods. (This latter process is essentially the method of Schuster, except that his periods are chosen successively, without criteria like those established by Clayton's method.)

Clayton's methods also have an advantage in indicating abrupt changes of phase in a periodicity such as frequently occur in periodicities related to sunspot-phenomena (because of the limited duration of particular active areas). These phase-shifts introduce breaks in the continuity of the lines in the phasograms without, however, changing their slopes.

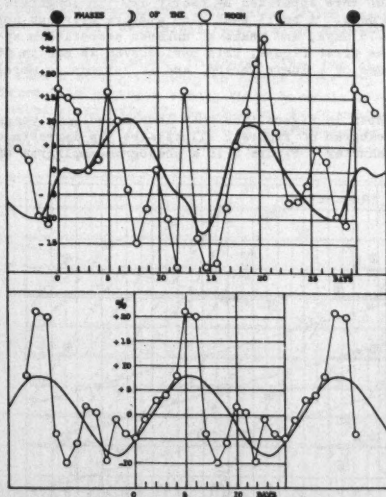


Fig. 1--WBBM data summed (upper) for 29.5-day trial period, curve being for harmonic mean with 15-day period, and (lower) in the 14.75-day second harmonic lunar period, curve being obtained by harmonic smoothing with 15-day trial period

In Figure 1, the upper figure represents WBBM summed up within a trial period of 29.5 days, the small circles being the means of each day within this period. Although the resultant curve is highly irregular, a double-frequency period seems to be shown, which is brought out more clearly by smoothing the means by harmonic analysis within a 15-day trial period, giving the curve shown in heavy line. As the important period appears to be about half the lunar period, or 14.75 days, in the lower part of figure WBBM has been summed up in a 14.75-day trial period, and the means smoothed by harmonic analysis within a 15-day period.

As a matter of interest, although not strictly relevant to the present inquiry, the phases of the Moon in the chosen trial-period have been entered on the Figure. It will be noted that minima occur just before new and full Moon, which agrees with Stetson's findings. In the lower graph, both new and full Moon occur at 0 and 14.75 on the day-scale.

While this figure very clearly shows a double-frequency or tidal effect within the lunar period, it is not in itself conclusive, as those familiar with this method of discovering hidden periodicities will

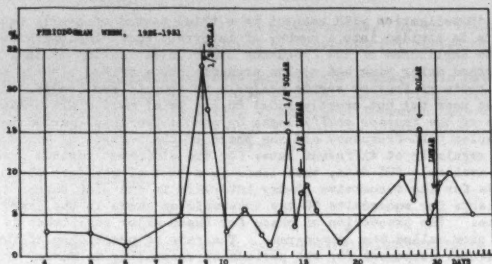


Fig. 2--Periodogram-plot for WBBM data (Schuster method)

realize. As a matter of fact, this method often shows false periods of considerable amplitude when applied to relatively short series, which smooth out and disappear when the data are sufficiently extended.

Figure 2 is a periodogram of WBBM, constructed by taking means of the data for each day within a number of different trial-periods, and determining the amplitudes by harmonic analysis. Large amplitudes are shown at or near the fundamental, second, and particularly the third harmonic of the solar rotation-period of 27.5 days, which is interesting in view of the six-year period covered by the data. It would seem that some of the active areas on the Sun (presumably not continuously accompanied by sunspots) remained approximately in the same solar longitude for a considerable part of the six years, particularly groups which were separated by nearly 120° in longitude, as indicated by the peak at about nine days. A small peak also appears near but not exactly at the half-lunar period of 14.75 days, and peaks of unknown association appear at 11, 25 and 33 days. As with the first figure, this periodogram is not in itself conclusive evidence of the existence of a lunar period, and is introduced merely for cumulative effect.

The method of periodic analysis shown in Figure 1 is that introduced many years ago by Balfour Stewart, while the periodogram of Figure 2 illustrates the improvement on Stewart's method later devised by Schuster. Figure 3 is a phasogram-ampligram of

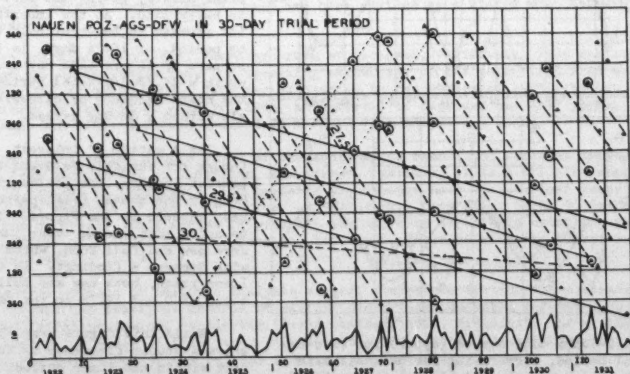


Fig. 3--Phasogram and ampligram for POZ-AGS-DFW (30-day trial period), and reception at Washington, D. C. (by Clayton method); note evidence for important 27.5- and 29.5-day periods

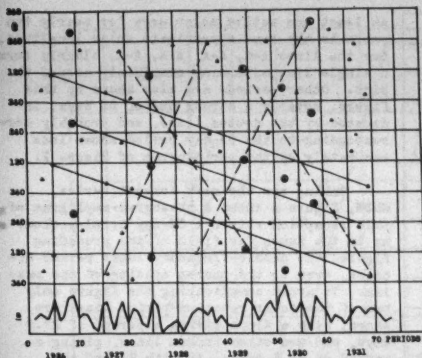


Fig. 4--Phasogram and ampligram plots for WBBM by Clayton method (30-day trial period); note persistent evidence for 27.5- and 29.5-day periods

Nauen using Clayton's method, extending over 120 trial-periods of 30 days, and the three full lines extending across the plot have a slope corresponding to 29.53 days. This is closely the lunar synodic period of 29.531 days; also, the double-frequency lunar-period is shown by the middle line. The upper and lower lines in the phasogram are merely repetitions of each other, 360° apart in phase, but the middle line, roughly half-way between, seems to clearly show the double-frequency or tidal effect. It is assumed that the larger maxima in the ampligram indicate times when the phases of three or more of the periods present come together, and the secondary maxima that two periods are in the same phase. This figure is the strongest evidence yet adduced for the lunar period, partly because of the length of the series, and partly

because of the close correspondence of the period found and the true lunar-period. Referring to Figure 1, it will be noted that the maxima in the upper graph are not exactly a half-period apart, but are spaced about 12 days apart, or, in the lunar period, 157° . Similarly, the middle full line in Figure 3 is not 180° below the upper line, but is approximately 160° below, which is again a rather close correspondence between intervals determined by different methods.

Figure 3 also shows, in broken line, the 27.5-day or solar rotation-period. These show a strong tendency to groups about 120° apart, confirming the periodogram of Figure 2 in giving a strong third harmonic of the solar rotation-period. It has been noted previously (H. H. Clayton, *World weather*, 1923, p. 298) that areas of solar activity, particularly in times of sunspot-maxima, have a tendency to group themselves 120° apart in solar longitude. This figure also gives evidence of the persistence of

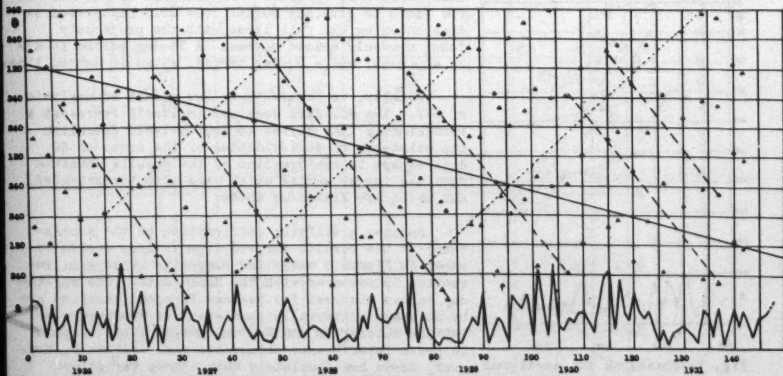


Fig. 5--Phasogram and ampligram plots for WBBM by Clayton method (15-day trial period); note evidence for prominent 14.78- and 13.92-day periods

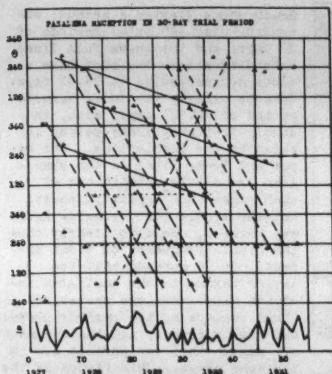


Fig. 6--Phasogram and ampligram for Brown reception-series (San Francisco as received at Pasadena, California), 30-day trial period

14.76, rather than 29.5 days, WBBM has been subjected to harmonic analysis in a trial period of 15 days, with the result shown in Figure 5. The full line crossing the phasogram gives a period of 14.78 days; a close correspondence with the true lunar half-period of 14.766 days. Other periods are indicated by the broken lines of slope 13.92 days, and the dotted lines of period 15.82 days.

The third reception-series, Pasadena reception from San Francisco, has been of peculiar interest for the reason that previously little or no correlation has here been found with solar activity or terrestrial magnetism. However, harmonic analysis of this series, shown in Figure 6, brings out very

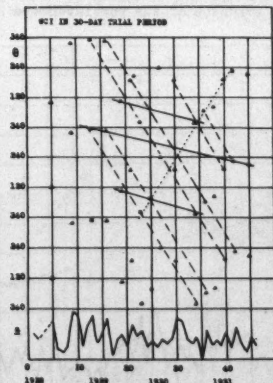


Fig. 7--Phasogram and ampligram for WCI reception (30-day trial period); note continued persistence of evidence of 27.6- and 29.5-day periods

clearly a solar period of 27.5 days, in pairs of lines separated by 120° . And although the series was too short to give any points, the 29.5-day period is also shown by the full lines, with the previously found unevenly spaced maxima. A 33-day period is also apparent, and a 30-day period, shown in dotted line.

Taking now the next longest series, WBBM, Figure 4 shows a phasogram-ampligram of this reception within a 30-day trial-period. As in the Nauen day field of the preceding figure, the double-frequency lunar period appears, even to the uneven spacing of the maxima. To avoid complicating the figure only two of the solar rotation-period lines are shown, with a slope giving a period of 27.5 days, and two other broken lines, giving a period of 33.5 days. As with Nauen, the phasogram also indicates a persistent 120° spacing of the solar lines, when these curves are all filled in the plot.

Inasmuch as the foregoing figures indicate that the predominant lunar period is

Finally, in Figure 7, is the result of analysis of WCI. The WCI-data does not in itself represent a sufficiently long series to conclusively establish the existence of periodicities of the order of 30 days except in confirmation of the results obtained from the longer series which were also investigated, and which are discussed above.

Another gratifying confirmation of the consistency of the results derived from various series is shown in Figure 8 where the composite of 10 a.m. reception is compared with the Nauen data. The day-to-day values observed for various European stations are by no means universally consistent at Washington or between Washington and Boston, due no doubt in part to phase interference phenomena, etc. Figure 8, however, shows how completely such chance variations tend to cancel out in the Washington low-frequency series. This is considered to offer further evidence for the real significance of the results. Thus, the period for the weighted mean of 10 a.m. reception

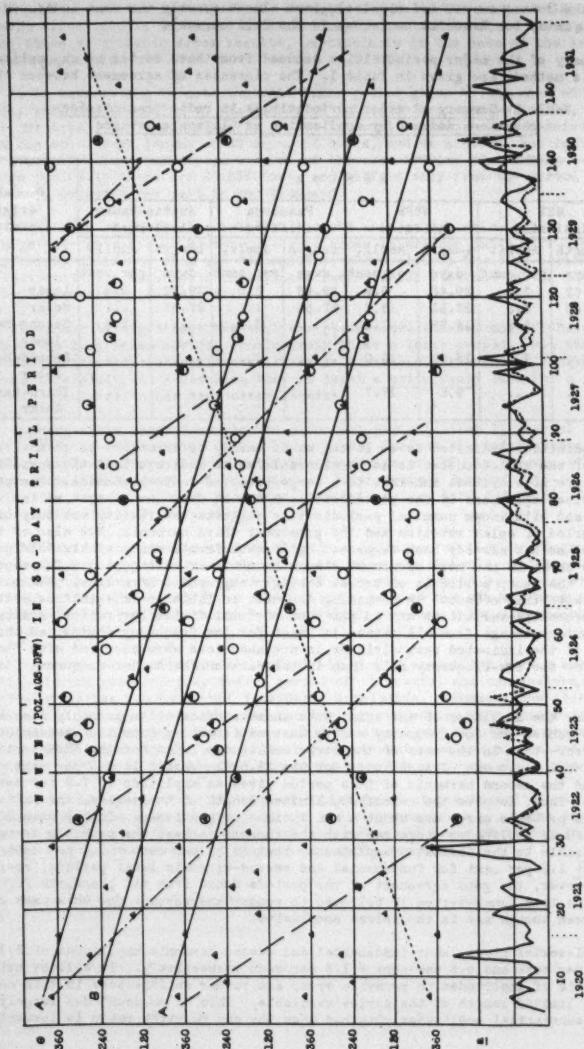


Fig. 8--Comparison of phasogram-ampligram plots for Nauen reception (solid lines and triangles) and average 10 a.m. reception (dotted lines and circles)

(shown in the dotted curves and circles) gives almost exactly the same indicated period as these data, for Nauen alone (shown in the full curves).

A summary of the major periodicities deduced from these series by an application of Clayton's methods are given in Table 1. The closeness of agreement between the

Table 1--Summary of major periodicities in radio transmission-phenomena deduced by application of Clayton's methods

Nominal length period	Series								Probable origin period
	WCI indicated		WBBM indicated		Pasadena indicated		Austin-Nauen indicated		
	Length	Ampli.	Length	Ampli.	Length	Ampli.	Length	Ampli.	
days	days	per cent	days	per cent	days	per cent	days	per cent	
29.5	29.62	3.1	29.42	5.9	29.46	2.0	29.52	0.3	Lunar
27.5	27.50	4.3	27.53	15.2	27.52	...	27.53	...	Solar
14.75	.....	5.6	14.78	7.5	.....	3.0	.....	1.5	Second-harmonic lunar
13.8	.....	7.1	13.92	15.0	.....	...	.....	...	Second-harmonic solar
9.2	.....	...	9.2	17.7	.....	...	.....	...	Third-harmonic solar

major periodicities indicated is so strong as to hardly be imputable to chance, and the diversity of the series chosen is so considerable as to indicate that the periodicities found are more or less inherent to a large group of radio phenomena. The surprisingly close agreement of the periodicities computed from the diverse series with each other and with known cosmical periodicities suggests the reality not only of the familiar period of solar rotation and its prominent third harmonic, but also of the lunar period as has already been suggested by Stetson from a study of his WBBM data and as here shown of the more prominent second harmonic at this period. The second harmonic of the lunar period is of course strongly suggestive of a tidal phenomenon in connection with this effect. In comparing the data in Table 1, it should be noted that the percentage-variations are in per cent of total fields (or ratios) and that the total percentage-change from all causes is least for low-frequency fields, so that the importance of the indicated periodicities is not much less when compared with the total variation for the low-frequency data than in the case of the higher-frequency field intensities.

However, the smallness of the components under consideration probably does have a tendency to render the low-frequency series less satisfactory from the standpoint of probable error--thus in the case of the large amplitudes found for the WBBM-series, the fundamental component of amplitudes for the 29.5-day period is 5.9 per cent + 1.5 per cent and the second harmonic of this period gives an amplitude of 7.5 per cent + 1 per cent. Thus, despite the relatively limited length of the series, the ratios of amplitude to probable error are about 4 and 7 times respectively. In the case of the smaller Pasadena amplitudes (together with the shorter series) the probable error becomes comparable to the indicated amplitudes, that is, 2 per cent + 1.5 per cent and 3 per cent + 1.5 per cent for fundamental and second-harmonic lunar periods, respectively. However, the good agreement of the periods found from the phasogram for this case with the true lunar-period is believed to render the results for this case of interest, even though not in themselves conclusive.

The WCI-series gives lunar fundamental and second-harmonic amplitudes of 3.1 per cent + 1.0 per cent and 5.6 per cent + 1.5 per cent respectively. It will be noted that the ratio of amplitudes to probable error are rather satisfactory in this case, despite the limited length of the series available. This is no doubt due largely to the fairly substantial amplitudes obtained when the day to night ratio is investigated.

In the case of the Nauen-series, the amplitudes and probable errors are 0.3 per cent + 0.17 per cent for the fundamental and 1.5 per cent + 0.24 per cent for the

second harmonic of the lunar period. Here the length of the series holds down the probable error despite the small indicated amplitudes and a rather satisfactory ratio of amplitude to probable error results, particularly in the case of the larger second-harmonic amplitude.

It is interesting to note that the lunar period given by the mean of these four series, weighted according to the number of points determining each line, is 29.528 days; the true lunar synodic month, or the interval between two successive new or full moons has an average length of 29 days, 12 hours, and 44 minutes, but individual months vary nearly 13 hours, mainly on account of the eccentricity of the Moon's orbit. This average period is therefore 29.531 days, and differs only from the period found by 0.003 day, or about one part in ten thousand.

It is also of particular interest to note that as arbitrary a parameter as the WCI night-to-day ratio at Boston (which is known to present quite different properties at different distances from the transmitter) shows clearly the same periodicities as are indicated from mean field intensities from distant stations in the low-frequency and broadcast-frequency regions.

It cannot be urged that the analysis given above for any one of these series, save perhaps the long Nauen series, conclusively shows a lunar period. But the detail agreement between these separate analyses is too close for even the long arm of coincidence to explain; it would seem that at least a prima facie case for a lunar period in radio transmission had been established.

Summary--This paper investigates prominent periodicities in several available series of radio-transmission data. These series include the low-frequency reception of WCI near Boston from 1928 to date; the reception of WBBM in Chicago (770 kc) near Boston from 1925 to date; the reception of low-frequency European stations at Washington (Austin series); and the reception of San Francisco (KPO and KWFI), California, at Pasadena (Howell C. Brown series).

The series are investigated by Clayton's extension of the periodogram methods of Balfour Stewart and Arthur Schuster, and all show unmistakable evidence of the solar period of rotation and its prominent third harmonic. Moreover, strong evidence is also found in all the series for a lunar period, such as has already been suggested by Stetson, with a prominent second harmonic which suggests a Kennelly-Heaviside-layer tidal phenomenon.

The series available are all relatively short (except the Austin series, which is available with good accuracy over a period of ten years) and conclusions based on any particular series are hence not considered conclusive. However, the close agreement between the periodicities indicated for the various series when independently treated are believed to be beyond that which could reasonably be imputed to chance. Thus, the periods found agree in all cases within one per cent, and are within one per cent of the known periods of the cosmical phenomena to which their origin is attributed.

The close agreement in the periodicities found is considered of particular interest in view of the wide diversity of the radio-transmission phenomena investigated and apparently indicates the importance of both solar and lunar phenomena in radio transmission over a wide portion of the present radio spectrum.

Tufts College,

Tufts College, Massachusetts

PROGRESS IN THE STUDIES OF COSMIC CORRELATIONS WITH RADIO
RECEPTION AT THE PERKINS OBSERVATORY

Harlan T. Stetson

Studies of the correlation of radio reception with solar activity have been made at the Perkins Observatory since March 1930. Over 1,400 hours of measured intensities of the carrier-wave from WBBM, Chicago, have been secured since the inauguration of the program. During 1930 quantitative measures of radio reception were determined for the 9:00 to 10:00 p.m. hour eastern standard time, and since March 1931 the observation-period has extended from 9:00 to 10:00 p.m. and from 12:00 midnight to 2:00 a.m. on WBBM, the hours from 10:00 to midnight being utilized for recording intensities of WJZ.

Solar photographs have been obtained daily in cooperation with the Mt. Wilson, Yerkes, and Naval observatories, the heliographic positions of sunspots being forwarded to Washington to supplement the data secured there.

An analysis of the recorded data for the two years, 1930 and 1931, has been completed and shows an increase in the intensity of the received carrier-wave from Chicago of nearly 400 per cent during the interval, while the sunspot-numbers have declined approximately 50 per cent (curves A and C of Fig. 2).

Utilising the longer series of evening observations made in 1931, it has been possible to determine a correlation-curve between radio intensities and the depression of the Sun along a great circle arc below the horizon. By means of this curve corrections for a "twilight-effect" have been determined for Delaware and reductions have been made for all observations over the two-year period to an adopted standard for corrected intensities; the expression "corrected intensity" in this instance being defined as the intensity of radio reception reduced to the condition of the Sun at the equinox and depressed 30° below the horizon. This represents the average condition of solar altitude throughout the year at the middle of the 9:00 to 11:00 p.m. hour at latitude 40°.

The application of this correction for twilight-effect has materially modified the curve for received signal-strengths. Inspection of curve B shows that a much closer inverse correspondence of radio reception with sunspot-numbers results. When signal-strengths are plotted logarithmically so that values increase with decreasing

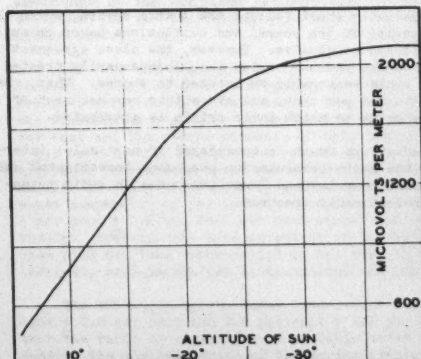


Fig. 1.—Curve showing increase of radio intensities of WBBM as received at Delaware, Ohio, with angular depression of Sun below the horizon at receiving station

ordinates, the graph of radio reception (curve C) strikingly parallels the graph of sunspot-numbers (curve D) during the past two years.

The intensities of ultra-violet radiation (Mt. Wilson values) have been plotted in curve D for purposes of comparison. The fact that the radio-intensity curve corresponds more closely with the sunspot-curve than with the ultra-violet radiation suggests that the apparent change in level of the Kennelly-Heaviside layer is in some way dependent upon the actual outbreak of sunspots.

The longer series of observations have afforded new material for a study of the correlation of radio reception with the position of the Moon, a problem reported upon at the 1931 meeting of the Geophysical Union. The detailed analysis of radio observations for

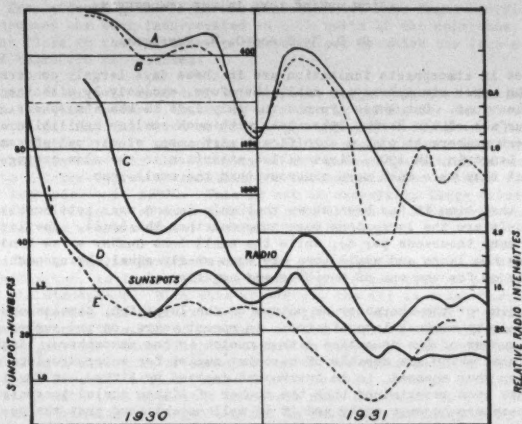


Fig. 2--Correlation of radio reception with Wolfer sunspot-numbers from observations at the Perkins Observatory: (A) Received intensities, linear scale; (B) received intensities corrected for angular depression of Sun (twilight-effect); (C) corrected values of radio intensities plotted on logarithmic scale; (D) three-months moving averages of sunspot-numbers; (E) relative ultraviolet radiation from the Sun (Mt. Wilson values), three-months moving averages

a study of lunar correlations has been undertaken by Josef Johnson, research assistant at the Perkins Observatory. The luni-tidal factor has been determined for each half-hour of radio observations, and a complete report of this more extensive investigation will be forthcoming shortly.

The theoretical work of Pederson and Egedal suggests that there may be a marked change in the ionization level of the Earth's atmosphere resulting from equilibrium atmospheric tides. As mentioned in my note in the 1931 report, Egedal has shown that auroral observations indicate large variations in the conductivity of the atmosphere at latitude 40° in the 100-km region directly traceable to an atmospheric tide. Egedal concludes, "The existence of a resulting enormous variation of the height of the conducting-layer may be tested by means of radio waves."

The results of Mr. Johnson's investigations should add very materially to the observational evidence for or against a true lunar correlation, especially since the Delaware data comprise widely differing hour-angles of the Moon during a single evening's observations.

Acknowledgment is again due the Rumford Committee of the American Academy of Sciences and the American Association for grants to make possible the continuance of these investigations.

Perkins Observatory,
Delaware, Ohio

SLOW-MOVING IONS IN THE ATMOSPHERE

G. R. Wait and O. W. Torreson

Studies in atmospheric ionization are in these days largely concerned with conditions in the upper atmosphere and deal, therefore, exclusively with the so-called small ions and electrons. But these are not the only ions in the atmosphere. Lower down, near the surface of the Earth, other ions with much smaller mobilities are encountered in sufficient numbers to play a significant part among electrical phenomena of the atmosphere. Langevin, in 1905, first called attention to the slow-moving ions and announced that they were much more numerous than the small ions.

Since that time it has been shown that only in and near settlements or communities of people are the large ions more numerous than the small. The large ions there may number many thousands per cc, while the small ions number a few hundred; in the open country the large and small ions are more nearly equal, being each of the order of 1,000 per cc for the sum of positive and negative.

In studies of the character or nature of the large ion, simultaneous measurements have been made by various investigators, in recent years, on the number of large ions and on the number of the so-called Aitken nuclei in the atmosphere. Aitken nuclei are those particles which are capable of becoming nuclei for water-droplets and which are counted, when thus encased, in an instrument devised by Aitken, an Englishman, in 1889. It has been ascertained that the number of Aitken nuclei increases greatly when a clear atmosphere becomes smoky and it is well established that the nuclei in the vicinity of large manufacturing communities are much more numerous than they are in the open country. When there is an increase in Aitken nuclei, it has been found by the present authors, and by others, that there is also an increase in the number of large ions. In fact, it appears from a very considerable series of observations with our large-ion apparatus, made simultaneously with measurements of Aitken nuclei entering and leaving the large-ion counter, that all large ions are derived from Aitken nuclei.

Another phase of our work has shown that both positive and negative large ions are in practically equal numbers in the atmosphere. Thirty-six sets of observations, in which positive and negative large-ion numbers were determined alternately and not many minutes apart, give an average for the positive of 3,600 per cc and for the negative 3,300.

Various laboratory experiments, though not conclusive, have indicated that each large ion, like each small one, in general carries only one electronic charge. In the present discussion, as in all discussions of large-ion numbers, it is assumed that a single electronic charge is carried by each large ion.

The apparatus with which the measurements of large ions have been made was put into operation on the grounds of the Department of Terrestrial Magnetism during the latter half of last year. Until the beginning of March of this year, only eye-readings could be made, but at that time the apparatus was converted to a recorder. Since it has been possible to record only one sign of large ion at any one time, the measurements of the past two months have been confined entirely to the positive ion.

In the schematic diagram (Fig. 1) the large-ion counter is represented by the horizontal set of three concentric cylinders. These cylinders are about two meters long. Air is drawn at a constant known rate between the central and intermediate cylinders, the adjacent surfaces of which are six mm apart. A potential difference of about 1,000 volts is applied between the intermediate and outer cylinders, the outer cylinder being connected to earth. The central cylinder, well insulated, is connected to the measuring-device, in this case a single-fiber electrometer. During recording, the charge on the central cylinder and fiber, although varying according to the ionic content of the atmosphere, is maintained at a fraction of a volt from earth, as a result of the flow of ionic charges through a high resistance, 10^{12} ohms (not shown in the diagram), which is connected between the central cylinder and earth. With this apparatus all ions with mobility greater than 0.0004 cm per second per volt per cm will be collected. However, the smaller vertical set of cylinder at the left in the diagram is of such dimensions and employs such a potential as will remove all ions with mobility greater than 0.3 cm per second per volt per cm, thus preventing

the small ions from affecting the large-ion measurements. The Swann modification of the Ebert ion-counter has been incorporated in both units of the apparatus, thus guarding against field at the entrances of the counters by which the ions might be driven away and therefore not counted.

Sixteen complete days of record of the positive large ions were obtained during March. A diurnal-variation curve, based on mean hourly values for the sixteen days (Fig. 2) shows two maxima, the first between eight and nine o'clock and the second just twelve hours later. It is not unlikely that the replenishment of fires in the morning and evening in homes in the vicinity of our observing-station in northwest Washington is to a large degree responsible for the maxima. The average value of positive large ions per cc is 4,800. This is not an especially large value. It is probable that in the vicinity of such manufacturing cities as Pittsburgh and Cleveland we would find the average number several times as high.

The United States Public Health Service has recently installed, at Seventh and B streets in Washington, an instrument for measuring the quantity of pollution deposited out of the atmosphere. With this apparatus, the air is drawn through filter-paper for a stated period (15 minutes) and the degree of blackening of the paper determined by comparison with a set of standard shades supplied with the instrument. Twenty shades are provided, each slightly darker to represent the additional deposition of one-third of a milligram of material out of one cubic meter of air. Through the courtesy of the Director of the Public Health Service, records obtained by Dr. J. E. Ives in March with this apparatus have been made available to us. The similarity of the diurnal variation in large ions and in pollution as measured by the air-filter is readily seen when the two curves are compared (Fig. 2). There can be little doubt that both types of pollution come from associated sources if not from the same one. A simple calculation, based on reasonable assumptions as to size and

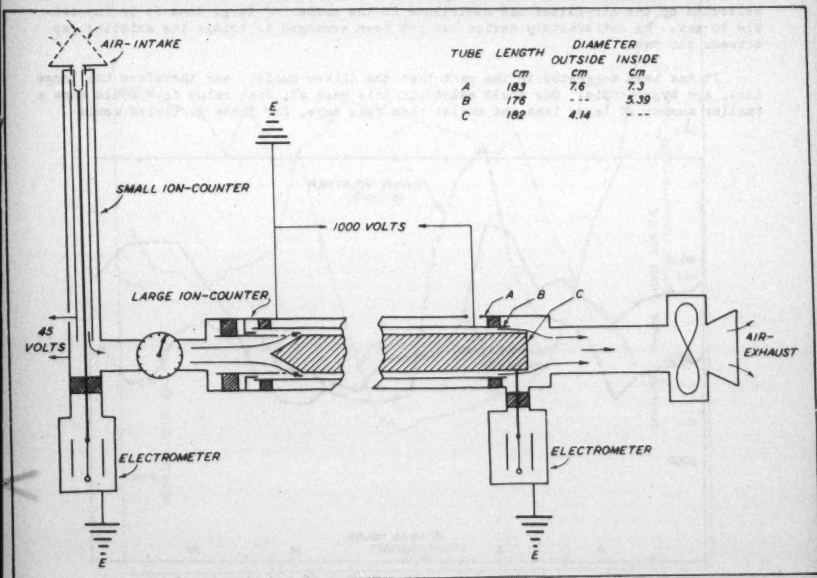


Fig. 1--Schematic diagram small and large ion-counters

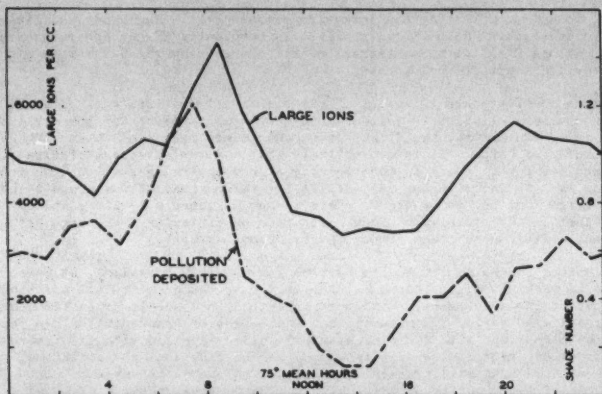


Fig. 2--Comparison diurnal variation large ions and atmospheric pollution, Washington, D. C., March, 1932 (pollution record courtesy U. S. Public Health Service)

density of the large ions, shows that the latter cannot contribute an appreciable amount to the pollution as measured by the air-filter, but to what extent the material collected by the air-filter can contribute to the number of large ions it is impossible to say. No satisfactory device has yet been arranged to bridge the existing gap between the two.

It has been suggested in the past that the Aitken nuclei, and therefore the large ions, are hygroscopic. One would expect, if this were so, that rainy days would show a smaller number of large ions and nuclei than fair days, for these particles would

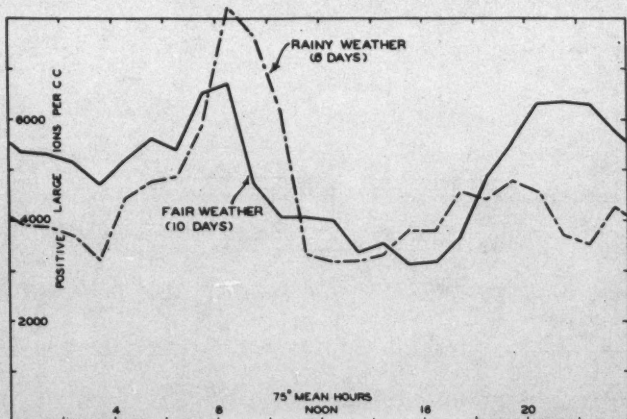


Fig. 3--Comparison diurnal variation number of positive large ions in fair weather and in rainy weather, Washington, D. C., March, 1932

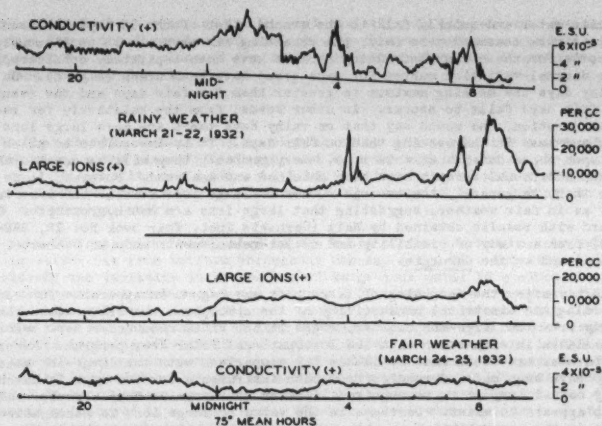


Fig. 4--Typical photographic records reciprocal relationship between large ions and conductivity

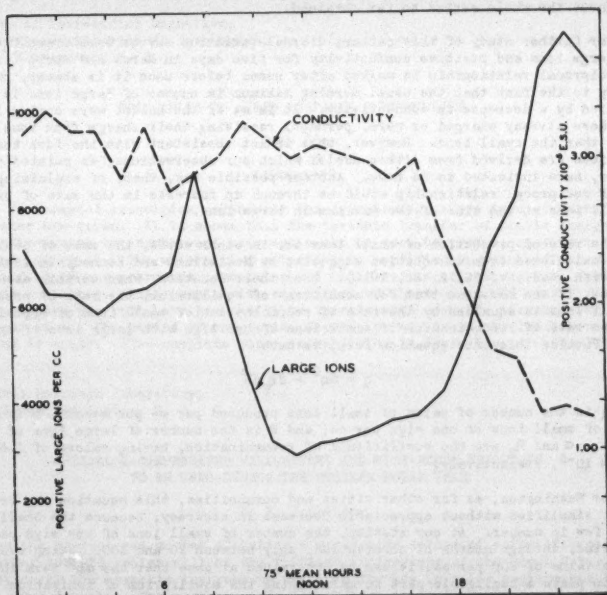


Fig. 5--Comparison diurnal variation large ions and conductivity Washington, D. C., March and April, 1932 (5 days)

accumulate water and quickly fall to the ground. Ten of the 16 days in March on which large ions were measured were fair, the remaining six were almost continuously rainy. The records for these two contrasting periods have been separately considered and average diurnal-variation curves for each group have been drawn (Fig. 3). On the curve for rainy days the morning maximum is greater than for fair days and the evening maximum of fair days fails to appear. In other words, from the relatively few records under consideration, one would say that on rainy days there are more large ions in the morning and less in the evening than on fair days. It is impossible to place any great weight upon these details at this time. Very probably they will be considerably modified when additional records have been obtained and analyzed. However, it is important to note that, in general, the average number of large ions remains the same in rainy weather as in fair weather, suggesting that large ions are not hygroscopic. This is in accord with results obtained by Wait (Carnegie Inst. Year Book No. 28, 269-270, 1928-29) from a study of visibility and nuclei-measurements made at Watheroo, Western Australia, and on the Carnegie.

Shortly after the recording of large ions was begun, an apparatus for continuously recording the electrical conductivity of the atmosphere was set up less than 15 feet away from the large-ion counter, where it has since been under test before being sent to Alaska in connection with the International Polar Year program. Records from this apparatus have been made available for comparison with the large-ion measurements. Tracings have been made of records from both instruments for two days in March (Fig. 4), and only casual inspection is required in order to recognize that a reciprocal relationship appears to exist. Decrease in the value of large ions is accompanied by an increase in the conductivity, and vice versa. On the rainy day both elements vary much more than on the fair day, but the reciprocal relationship persists to a very marked degree. These records are representative of the relationship found generally throughout the whole series so far obtained.

For further study of this matter, diurnal-variation curves were drawn for positive large ions and positive conductivity for five days in March and April (Fig. 5). The reciprocal relationship is marked after noon; before noon it is absent, owing chiefly to the fact that the usual morning maximum in number of large ions is not accompanied by a decrease in conductivity. It is as if the nuclei were coming into the atmosphere already charged or were, perhaps, receiving their charge from some other source than the small ions. However, this is not consistent with the idea that all large ions are derived from Aitken nuclei which our observations, as pointed out earlier, have indicated to be true. Another possible way, then, of explaining the lack of reciprocal relationship would be through an increase in the rate of production of small ions at the time of the maximum in large ions.

The rate of production of small ions or, in other words, the rate of ionization, can be calculated from an equation suggested by McClelland and Kennedy in 1912 (Proc. Roy. Irish Acad., v. 30, A, 89, 1912). From their equation, when certain assumptions are made, it can be shown that for conditions of equilibrium, the rate of production of small ions is equalled by the rate of recombination of small ions of opposite sign plus the rate of recombination of small ions of one sign with large ions of opposite sign. Putting this into equation form, we have

$$q = \alpha n^2 + 2\eta_2 nN$$

where q is the number of pairs of small ions produced per cc per second, n is the number of small ions of one sign per cc, and N is the number of large ions of one sign per cc. α and η_2 are the coefficients of recombination, having values of 1.6×10^{-6} and 6×10^{-6} , respectively.

For Washington, as for other cities and communities, this equation may be still further simplified without appreciable decrease in accuracy, because the small ions are so few in number. At our station, the number of small ions of one sign per cc has varied, through months of observation, only between 20 and 200. Using even the maximum value of 200 per cc, it can be determined at once that the αn^2 term in the equation plays a negligible part in maintaining the equilibrium of ionization. The equation therefore becomes

$$q = 2\eta_2 nN$$

To determine by this equation the diurnal variation in the rate of ionization for the five days for which large-ion and conductivity observations were available, it was necessary first to derive values of the small-ion numbers from the conductivity data. This was done from the formula

$$\lambda = nek$$

where λ is the unipolar conductivity in electrostatic units, n is the number of small ions of one sign, e the electronic charge, and k is the mobility in cm per second per volt per cm. The mobility was taken as 1.6 cm. It is worthy of note that the small ion numbers obtained in this way all fell within the range of 20 to 200 per cc established by our previous work.

The rate of ionization, calculated on the basis of the previous considerations, resulted in values far from uniform throughout the day (Fig. 2). Actually, the curve follows closely the variation in the number of large ions until 16 o'clock, but thereafter the change in the number of small ions is sufficiently great to prevent the rise of the ionization-values to large figures. It is of interest to note that the average value of the rate of ionization is in good agreement with the rate deduced from considerations of the ionizing-effects of radioactive matter in the soil and in the air. The somewhat unusual ionization-curve which we here obtained was not unexpected. Eye-observations of large and small ions in earlier work (Nature, v. 129, 401, 1932), taken over several 24-hour periods, produced similar ionization-curves, except that the morning maximum occurred at a later hour. We do not know what such an ionization-curve may mean. Possibly our ionization-equation does not adequately represent the facts. Possibly, on the other hand, there is this diurnal variation in the rate of ionization, even though it is difficult now to see that it can exist.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

PRINCIPLES OF A NEW PORTABLE ELECTROMETER

Ross Gunn

(Abstract)

The fundamental principles underlying the operation of a new type of portable electrometer are given. It is shown that the periodic transfer of static charges from one capacity-system to another and back again can be used to produce an alternating electrical potential. The alternating potential is amplified by means of vacuum-tubes, then rectified by a synchronous commutator and the resulting direct-current used to operate an indicator. Instruments with capacities of about 15 cm and sensitivities of 10^4 microamperes per volt have been built to operate with portable microammeters used as the indicator. The period of the device depends primarily on the indicator employed and is small. (The complete paper is published in Phys. Rev., v. 40, 507-512, 1932.)

U. S. Naval Research Laboratory,
Bellevue, Anacostia, D. C.

OPTICALLY-COMPENSATED VARIOMETERS AND WIDE-RANGE RECORDERS TO BE USED DURING THE JUBILEE POLAR YEAR

H. F. Johnston

When the project was mooted of making a world-wide series of scientific observations during 1932-33, which will be the fiftieth anniversary of the first Polar Year, the question of the magnetic instruments suitable for use in polar regions had to be given careful thought. The problem of transportation is serious and requires that the minimum possible weight of building materials be taken, with consequent restriction in the size and insulation of the observatories. Fortunately for the scientific expedi-

tions which will proceed to the polar regions, Dr. D. la Cour, of the Danish Meteorological Institute, who is President of the International Polar Year Commission, and his associates had realized the lack of appropriate magnetographs and had designed apparatus adequate for the purpose.

These instruments combine several advantages. They are optically compensated for changes in temperature; hence an elaborately insulated building for housing them is not necessary. The magnets employed are of small magnetic moment; thus the building may be of comparatively small dimensions. Above all, the cost of a complete magnetograph is low, being of the order of \$500—a most important factor in this time of financial stress.

The horizontal-intensity instrument which has been named the "Copenhagen variometer" by its designers, D. la Cour and V. Laurson (Copenhagen, Inst. Mët., Comm. Mag., No. 11, 1930), has given satisfactory results during tests under polar conditions. It embodies a number of advantages. The magnet is 8 mm long, weighs 25 mg, and has a magnetic moment of less than one c.g.s. unit. The direction of the magnet with reference to the mirror may be readily changed. The magnet is supported by a quartz-fiber, on each end of which is a pear-shaped piece of quartz that fits into a conical holder and wedges itself tightly. A prism is used to compensate for changes in temperature. The arrangements for temperature-compensation are mounted separately, and all adjustments to the light-beam may be made without disturbing the suspended magnet.

Figure 1 is taken from magnetic communication No. 11 of the Danish Meteorological Institute, and shows in a schematic way the arrangement of the various parts of the instrument.

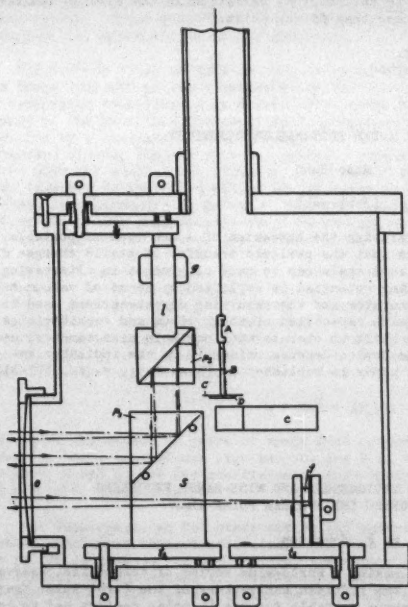


Fig. 1.—Schematic arrangement Copenhagen variometer

The letters designate the following parts: A, the point of attachment of the lower end of the fiber; B, the mirror for the suspended magnet; C, an aluminum disc to which is attached the magnet; D; P_1 , the compensating prism, is silvered on its upper one-third part to give a record of its movement and hence a record of the temperature; S , the bimetallic strip for suspending the prism; g, the holder for the bimetallic strip which is arranged for changing the effective length of the strip; t_1 , a semi-circular disc bearing the compensating parts, which is attached by three screws to the cover of the instrument—the screws project through the cover and there are stiff springs between the disc and the cover permitting the compensating prism to be adjusted without opening the instrument; P_2 , the auxiliary prism required by the optical arrangements; f, the fixed mirror used for the base-line; s, t_2 ; S, an opening in the support for the auxiliary prism so that light may reach the fixed mirror; t_2 and t_3 , semi-circular discs on three-point supports for adjusting the auxiliary prism and the fixed mirror; o, an adjustable copper block to provide damping. The paths of the three light-rays for temperature, horizontal in-

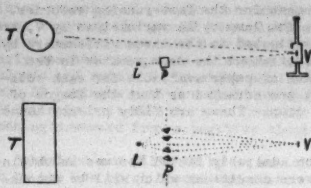


Fig. 2--Diagrammatic arrangement regular magnetograph-recorder

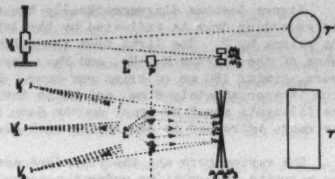


Fig. 3--Diagrammatic arrangement fast-running recorder

tensity, and base-line are shown by lines marked with arrows to show the direction of the rays.

The instrument for measuring vertical intensity has been named the "Godhavn balance" by its designer, D. la Cour (Copenhagen, Inst. Mët., Comm. Mag., No. 8, 1930). The magnet, mirror, and knife-edges are made from a single piece of tungsten-steel. The magnet-system is 6 cm long, weighs 2.5 grams, and has a magnetic moment of approximately 100 c.g.s. units. The magnet is supported on saddle-shaped agates in a sealed chamber where the air-pressure is reduced to 100 mm of mercury, thus eliminating effects of humidity and dust. Temperature-compensation is by means of a prism supported by a bimetallic strip. The fixed mirror and apparatus for temperature-compensation is enclosed in a chamber above that where the magnet is placed, so that adjustments may be made without disturbing the magnet.

The magnet may be balanced easily by abrading it with a piece of carborundum. The desired scale-value may be obtained by using an appropriate orientation of the magnet. For a particular magnet-system the following approximate scale-values were obtained: When the north end of the magnet was north, the scale-value was 16γ per mm; when east, 10γ per mm; and when south, 5γ per mm.

Since the changes in the magnetic elements in the polar regions are of greater range than in regions near the equator, an adequate recorder for polar regions should be capable of registering wide ranges in the magnetic elements. V. Laurson, utilising the suggestions of Ad. Schmidt (Veröff. Met. Inst., No. 333, 38-45, 1926), has developed recorders suitable for registering great ranges in the magnetic elements. In these instruments use is made of several prisms to multiply the range of record.

Figure 2 shows diagrammatically the arrangement of the optical system for the recorder, whose drum rotates once in 24 hours. The drum is indicated by the letter Z, the lamp by L, and the variometer by V. Between the lamp and the variometer is placed a series of total reflecting prisms P. These prisms are oriented so that they reflect the light of the lamp upon the lens of the variometer. The light of the lamp after being reflected from the magnet-mirror forms a series of vertical images of the filament on the face of the recording-drum. The intervals between the images depend upon the distance between the prisms. That distance is so arranged that it is slightly less than the width of the photographic paper allotted to the particular variometer, in order that before one recording-spot leaves the paper the next appears. The range of the recorder is thus multiplied by the number of prisms. In the regular polar recorder there are eight prisms for the declination-variometer, six for the horizontal-intensity variometer, and four for the vertical-intensity variometer, and, since the spots are arranged at 100-mm intervals, the range in record is 800 mm in D, 600 mm in H, and 400 mm in Z, the absolute range of course depending upon the scale-value of the particular instrument.

The photographic paper for the regular recorder is 31 cm wide, one-third of which is allotted to each of the D-, H-, and Z-variometers. In order that the series of images from each of the variometers may not interfere and confuse the record, the variometers are placed at different heights. The diameter of the drum is approximately 12 cm, and the clock-work is arranged to give 15 mm of trace per hour.

Figure 3 shows diagrammatically the arrangement for the fast-running recorder. The recording drum is indicated by the letter T, the lamp by L, variometers by V, and the prisms by P. The light from the prisms is reflected to the three variometers by means of the mirrors M_1 , M_2 , and M_3 . For this instrument the drum rotates in two hours, giving 180 mm of trace per hour. The width of paper available for each rotation is approximately 8 mm, and hence the prisms are arranged so that the images of the filaments are 7 mm apart on the face of the drum. There are fifty prisms; hence the range in record is 350 mm for each element.

The variometers and the recorders seem to be admirably fitted for use in obtaining magnetic observations under the somewhat severe conditions which will be encountered in the polar regions.

Department of Terrestrial Magnetism,
Carnegie Institution of Washington,
Washington, D. C.

THE RELATION OF LIGHTNING-DISCHARGES TO CHANGES IN THE ELECTRICAL FIELD OF THUNDER-STORMS

J. C. Jensen

C. T. R. Wilson, Schonland, Craib, and others have published reports based on investigations in England and in South Africa which indicate that thunder-storms are bipolar with the upper pole positive in a majority of cases. The mechanism of the thunder-storm as described by Simpson, and based on his breaking-drop theory, requires that the anterior active portion of the cloud, where convection currents of ascending air are formed, shall be positively charged. Above and to the rear of this active area there is a less concentrated negative charge. This theory has been elaborated by Humphreys and recent field investigations by Banerji at Bombay are in general agreement with it.

Based on experiments with influence machines in the laboratory in which the branching of the discharge always goes from the positive pole toward the negative, Simpson has used as the criterion for determining the polarity of any portion of a cloud from which lightning-flashes proceed the direction of observed branching. A study of more than 400 lightning-photographs collected by him from various sources gave a ratio of more than three from positive clouds to one from negative. In view of the fact that the active part of the cloud should be small compared with the remainder, this is a surprisingly large ratio. It is also contradictory to the recent papers by Lewis and Foust, Bell and Price, Sporn and Lloyd, and by Peek, which show that almost all of the direct lightning-strokes to transmission-lines are from negative clouds and that the negative discharges are much more severe than the positive.

The writer has been making observations on the electrical field of thunder-storms for more than seven years, and summaries of the results obtained have been previously reported. During the last two years our efforts have been concentrated on an attempt to obtain as many lightning-photographs as possible for which the corresponding field changes were observed. The field changes were obtained by the use of an insulated metal deck connected through a sensitive galvanometer to ground. A beam of light through a right-angle prism to the galvanometer-mirror and back to a revolving-drum made the electrical record semi-automatic. Special care was taken to keep accurate and specific notes by the photographer as well as by the observer in charge of the electrical apparatus, the two observers being in constant telephone communication as well, so as to identify definitely each picture with the corresponding galvanometer-record. A battery of four micro-barographs, three in a north-and-south line 8-1/2 miles long, and the fourth four miles to the west, gave an accurate record of the path of the storm.

In twelve night storms during which pictures have been taken, a total of 366 flashes have been photographed and the field-change deflections have been observed for 185. Of these 77 show downward branching in discharges which reached the ground and the galvanometer-deflections indicated positive field-changes requiring the lower pole of the cloud to be negative. Thirteen discharges which reached the ground showed negative field-changes and came from a positive portion of the cloud. Several of these are

striking examples of positive branching with their many fine streamers. Eight discharges reaching the ground have distinct upward branching, four being accompanied by positive field-changes and four by negative. Eighteen show no branching although they clearly reached the ground. In some of these cases the fine streamers were obscured by clouds and rain. Forty-eight show branching across the sky but do not reach the earth, 29 having a positive field-change and 19 a negative one. The remaining 21 are indeterminate. It will be seen from the above summary that either there can be branching downward from a negative cloud or the observations are self-contradictory.

Schonland and Allibone in an article in "Nature" for November 7, 1931, have shown that by the use of an impulse-generator delivering over 3,000,000 volts they have been able to obtain branching from a negative point to a positive grounded plane. F. W. Peek, Jr., has sent me two photographs made in the General Electric laboratories which show branching from a negative point, one to a plane and the other to a point raised from a plane. He has also supplied photographs showing branching from a positive point to a negative plane, the streamers in this case being more numerous and attenuated. It is characteristic of my own photographs from a negative cloud that they consist of a very bright principal channel with but few light streamers, while those from a positive cloud are less concentrated and have many more streamers. This agrees well with the experience of the electrical engineers already cited that negative hits on their lines predominate over the positive and carry much larger charges.

From the above facts it is evident that Simpson's criterion for determining the polarity of a thunder-cloud by the direction of branching can no longer be accepted, and that his theory relative to the mechanism of thunder-storms will probably require revision at some points.

Nebraska Wesleyan University,
Lincoln, Nebraska

BLANK PAGE

Dr. H. H. Henshaw and Dr. J. H. Henshaw

At the time of the last meeting of the Union, the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

The members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel... the members of the Association were gathered at the Hotel...

AMERICAN GEOPHYSICAL UNION

Thirteenth Annual Meeting

REPORTS AND PAPERS

SECTION OF OCEANOGRAPHY

Washington, D. C.

April 29, 1932

CONTENTS

	PAGE
SECTION OF OCEANOGRAPHY	193
Progress of the Woods Hole Oceanographic Institution and cruises of the <u>At-</u> <u>lantis</u> . H. B. Bigelow and C. Iselin II	195
Oceanographic work at the Scripps Institution of Oceanography, University of California, La Jolla, California, July 1, 1931 to April 18, 1932. T. Way- land Vaughan.	200
Contributions of the United States Hydrographic Office to oceanography. A. B. McManus	207
Oceanographic work of the Coast and Geodetic Survey during the past year. Frank S. Borden	211
On the penetration of daylight into the sea. E. O. Hulburt.	224
Photoelectric measurements (made during the summer of 1930) of the penetration of light (wave-length 2,900 to 4,800 Angstrom units) in sea-water, and the results of laboratory photoelectric measurements (made during the summer of 1931) of the absorption-coefficient of sea-water. Burt Richardson.	225
Landslide-modification of submarine valleys. Francis P. Shepard	226
Microbiology and the marine limestone. Richard M. Field	230
Radium-content of ocean-bottom sediments. C. S. Piggot.	233
Temperature-gradients in ocean-waters. E. B. Stephenson	238
Progress in the investigation of surface-temperatures of the western North At- lantic. Phil E. Church	244
The recommendation of a program of hydrographical observations leading to the quantitative determination of Arctic and Atlantic interchanges. E. H. Smith	249
Oceanographic work of the United States Coast Guard during 1931 and plans for 1932. M. G. Ricketts	252
A recent tour of some oceanographic centers of northwest Europe. Charles F. Brooks.	253
Sea-temperatures by bucket on express liners. Charles F. Brooks	258

PROGRESS OF THE WOODS HOLE OCEANOGRAPHIC INSTITUTION AND CRUISES OF THE ATLANTIS

H. B. Bigelow and C. Iselin, II.

At the time of the last meeting of the Union, the laboratory of the Institution was just rising at Woods Hole; the research ship was being built in Denmark; and the scientific staff and program were in process of organization.

The laboratory was opened for occupancy June 1931; the Atlantis was delivered to her owners in Copenhagen in that same month; and the Institution has now been in full operation long enough for some account to be given of its plans and progress.

Most interesting, no doubt, for this meeting are the cruises that have already been made by the Atlantis, for the worth of this particular type of research ship has now been proved.

A year ago the officers and scientists of the crew of the Atlantis were just beginning to gather in Copenhagen. The time during May and June was employed in supervising the completion of the vessel and in getting together the scientific apparatus. On July 7 the Atlantis set sail for Plymouth, England. Since then the boat has been at sea almost continuously except during the months of September and January. Therefore, we can now report the result of about seven months work at sea and through a review of this beginning, a good estimate can be formed of what may be expected in the future from the Woods Hole Oceanographic Institution's cruises.

And it seems suitable in this report to stress the experiences at sea with the Atlantis because it is a new and exciting event to be able to report that at last an American scientific ship has been commissioned for continuous oceanographic investigations.

At this same meeting last year, a general description of the Atlantis was given, but now a few more words of explanation may be of interest. She is a Diesel auxiliary ketch of about 420 tons displacement and 142 feet in extreme length. Her sail area consists of about 7,200 square feet of canvas and her main engine, developing some 280 horse-power, can easily maintain a cruising speed of eight knots. Below decks her accommodations include cabins aft for a scientific staff of five and amidships a large laboratory at present mainly used for chemical work. On deck and also amidships is another laboratory where the biologists can examine and preserve the tow-net catches and where the samples are collected from the water bottles and the thermometers read.

The main trawl-winch, carrying 10,000 meters of one-half inch diameter cable, is located in the lower hold, but can be controlled from the deck. The hydrographic winch stands on deck just aft of the laboratory. Both winches are electrical and fitted with automatic devices for guiding the wire on the drums. Her cruises to date have proved that in every way the gear is well designed and entirely suitable for the work. We have not regretted the fact that the Atlantis is a sailing vessel and not a full-power type. The sails have proved their worth under stormy conditions, for weather has yet to be experienced so severe that a station could not be made. Under moderate conditions, especially in the tropics, the absence of engine-room heat and lack of noise and vibration are more obvious recommendations for this type of vessel. The fuel and water supply is ample for cruises up to two months in length, and by being careful with the water, she could remain out much longer, if necessary.

The first cruise, which was also the trial trip, began on July 16, when the Atlantis sailed from Plymouth, C. Iselin, II., in command. The initial objective was a line of stations following longitude 30° west and extending far enough north and south to cross the major branches of the easterly moving currents in the North Atlantic. The accompanying chart (Fig. 1) shows the approximate location of this section, as well as the other sections the Atlantis has run to date. These sections consist of about 250 stations. In the deep water the majority of them extend down to 3,000 meters, but at about every fifth station, observations have been secured to the bottom. Since the stations have seldom been more than 100 miles apart, and usually much closer, they give a very complete picture and should go far to help in the understanding of the circulation of the North Atlantic. Observations of temperature and salinity have been a routine part of all cruises to date, but they by no means repre-

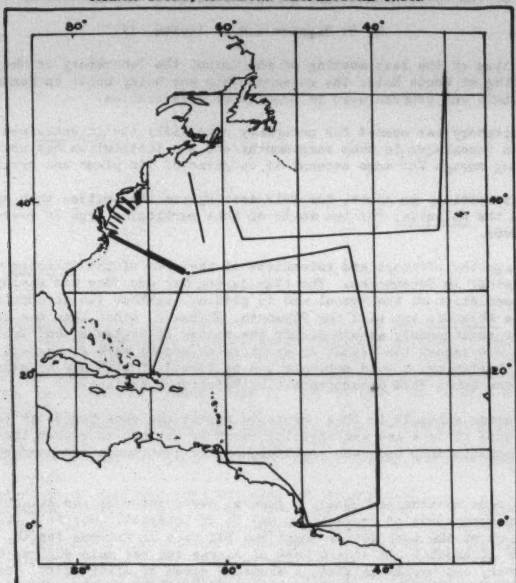


Fig. 1--Approximate location Atlantis sections, July 1931 to May 1932

sent all that has been accomplished.

On the first cruise, Dr. Frans Zorell, of the Deutsche Seewarte, carried out oxygen-determinations of all the water-samples collected. Dr. George Clarke was in charge of a special investigation of the penetration of light below the sea-surface. The Institution had secured a photoelectric apparatus, built under the direction of Dr. Atkins at the Plymouth Laboratory, where extensive observations of the influence of sunlight on the diurnal migration of the plankton in the English Channel had been carried out. The Atlantis, therefore, was merely continuing this work out into deeper water, but since the light there penetrates so much deeper, the work was considerably complicated. Of special interest, are the plankton-tows made in connection with the photometer-observations. Five simultaneous tows were made with closing-nets in such a way that the exact depth of each net was known, and these tows could be repeated at suitable intervals throughout the day so that an accurate picture was secured of the influence of light on the movements of the plankton.

On this cruise also the Atlantis made a number of eel tows for Prof. Johannes Schmidt. Using the same technique as has been developed on board the Dana, catches were made each evening mainly in regions where Prof. Schmidt had too few observations. These eel nets are two meters in diameter at the mouth and were sent down four at a time fastened at intervals to our heavy trawl-wire. In order to test out the main winch for deeper tows, a number of hauls were also made for deep-sea fish with good result.

After the Atlantis had reached Woods Hole, it was found necessary to make a few minor changes in the ballasting and rigging, so it was not until early in October that she was ready for sea again. Her next cruise was southward along the continental shelf to Cape Hatteras. This series of sections was planned to supplement the report

now in preparation on the coastal waters from Cape Cod to Cape Hatteras. The greater part of the observations have been made by the United States Bureau of Fisheries steamer Albatross, but no survey had been made for the month of October. The Atlantis completed 43 hydrographic stations in about eight days as well as a general plankton-survey of the region. Mr. H. R. Seiwel carried out pH- and phosphate-determinations of all the water-samples collected.

In November the first of the quarterly Bermuda cruises was carried out. The route chosen gave two sections, one from Nova Scotia to Bermuda and the other from Bermuda to the mouth of Chesapeake Bay. Mr. Seiwel again made pH- and phosphate-determinations at all the stations. On this cruise the first heavy weather was experienced and the vessel behaved satisfactorily, in spite of the fact that every effort was made to run the sections at full speed in order to get as near a simultaneous picture as possible. It is planned to repeat these sections four times a year until a satisfactory picture of the annual changes in the ocean has been obtained.

These three preliminary cruises having proved that the Atlantis could accomplish what she was sent out for, preparation was made for a more ambitious expedition, which started early in February. Here the main objective was a section extending from about 35° north to the equator and therefore crossing the northeast trade-wind belt and the northern equatorial current. At the same time it was possible to secure two good sections between Bermuda and Chesapeake Bay and a third crossing the Antilles Current. As a matter of fact, the Atlantis is not yet back from this 8,000-mile cruise, but as everything has gone well, there is every reason to believe that the work has been carried out as planned.

Again Mr. Seiwel was in charge of the chemical program, all water-samples being analyzed for oxygen as well as pH and phosphate. A special feature of his work was a chemical section along the equator giving the changes experienced as the Atlantis sailed from oceanic water into the influence of the Amazon River. Throughout the cruise, accurate vertical plankton-hauls were also made with a special net of fine monel metal screening, in order to correlate the distribution of plankton with the observed distributions of phosphates.

On this cruise also the collecting of plankton was begun for Dr. Wheeler, Director of the Biological Station at Bermuda, by means of oblique hauls with a two-meter net from 200 meters to the surface. The Atlantis catches should supplement the plankton-work at the Bermuda laboratory and it is hoped that gradually a general study of the distribution of zooplankton in the northwestern Atlantic will result.

Prof. Rossby of the Massachusetts Institute of Technology is in charge of our meteorological investigations. On this last cruise he sent with the Atlantis one of his students, who has secured good statistical data of the wind-directions in the lower layer of the atmosphere. About 200 balloon-ascent have been observed with a special theodolite. It is Prof. Rossby's hope that by means of this study a value of the frictional force between the wind and the sea-surface can be obtained, and thus a better understanding of oceanic wind-currents. At the same time a great many evaporation-measurements have been obtained, besides other more general meteorological observations. We might mention that some difficulty has been experienced aboard the Atlantis carrying out the meteorological program. The instruments have not stood up well against the dampness at sea, and we have had to go ahead slowly until we were sure just how much effect the sails and deck-openings had on the readings obtained in the meteorological shelter.

Finally on her way back up the coast from Chesapeake Bay, the Atlantis is now repeating her survey of last October and at the same time running two sections from the beach to the 1,000-fathom curve, taking bottom-samples every two miles. This is in connection with a study of the formation of the continental shelf, begun last summer by Mr. H. S. Stetson in the neighborhood of Cape Cod. A new type of bottom-sampler is being used which brings up each time a given quantity of the bottom, either sand or mud, in a watertight condition so that none of the fine washings are lost.

Such is the general nature of the work carried out with the Atlantis during the last ten months. Of course, it will be some time before the observations can be

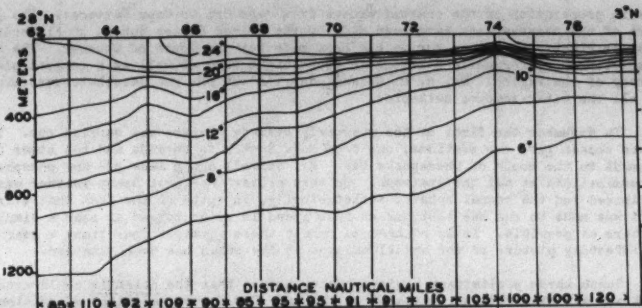


Fig. 2—Temperature-sections, March 1932, which follow closely longitude 40° west

published, but we can now draw some general conclusions based on our experience at sea. As mentioned before, we are well satisfied with the boat. She will do anything that a vessel of her size can be expected to do. Even in winter we can carry on after a fashion. Especially in the case of hydrographic and chemical work in the severe weather nothing can prevent the stations being made, provided the route chosen does not involve too much head-wind. For biological work heavy weather will always be a great hindrance. Only the strongest nets can stand hard usage. In the same way, meteorological observations are of little value when the spray is flying. In other words, within reasonable limitations, we can confidently expect the *Atlantis* steadily to progress in the exploration of the sea. Finally, it now seems fairly certain that she can be operated throughout the year and still keep within the limit of \$35,000 that the budget of the Institution allows.

Although the *Atlantis* is not yet equipped with sonic depth-finding apparatus, we have been reminded only too forcibly that oceanographers cannot yet take the depth of the water for granted. We now have a very good wire sounding-machine, but with a strong wind or a swift current this method is so difficult that we have not made sounding a routine part of our work. On several occasions in making a deep station where the chart appeared to show a level bottom, we have brought up the lowest water-bottle filled with mud, and twice it has been smashed beyond repair by hard bottom. On the last cruise, while working in a region about 600 miles east of Bermuda where the chart indicated about 2,800 fathoms of water, we struck hard bottom when the lowest water-bottle could not have been more than 1,800 fathoms below the surface. In other words, we encountered a submarine mountain rising more than a mile above the general level of the ocean-floor.

The only other results of our last cruise which we can discuss at this time, as the records are still on the *Atlantis*, is part of the north and south temperature-section. As shown in Figure 2, the section starts in about 28° north and extends nearly to the equator. Only the observations from the upper 1,400 meters have been plotted here, but the temperatures have been corrected for depth, so the section is accurate as far as it goes. The northern 300 miles of the section lie in the horse latitudes and although we should expect horizontal isotherms they are here seen slanted so as to indicate a westerly current which checks up with our navigational record for that part of the trip. The central 900 miles of this section lie across the belt of the northeast trades. As we sailed southward, the various isotherms continued to approach the surface, but their slope is by no means constant.

From our navigational record, it is evident that the current was running in streaks. Some days we would experience 15 to 20 miles of westerly current and other days none at all. Apparently the strength and location of these bands of current bore no relation to the strength of the wind along our route. Some indication of the streaky nature of the current can be found in this section, although we will have to wait for the corresponding density-profile to be sure. At about latitude 8° north we

struck a strong counter-current running directly to windward with such strength as to cause tide-rips on the surface. At the time the Atlantis was approaching the equator, no doldrum belt existed. We ran directly into the southeast trades where we experienced a very strong flow of westerly current. Since this is so near the equator, the strength of the rotational effect of the Earth is very weak, therefore, we should expect little distortion of the water-layers on the southern end of this section, as is indeed the case. Apparently there is an immense volume of water flowing in a westerly direction across the belt of the trades, but just how important a part the wind plays in its propulsion is a question for the future. Moreover it is not easy to reconcile this section with Eaman's well-known theory of wind-currents.

The researches so far carried out for the Atlantis may thus be grouped under the following headings: Dynamic studies of ocean-circulation by Frans Zorell and C. O. Iselin; distribution of oxygen in the water and of phosphorus compounds by Frans Zorell and H. R. Seiwel; penetration of light and vertical distribution of plankton by George L. Clarke; geographic distribution of various planktonic groups.

It has been recognized, throughout the development of the Institution, that many important oceanic investigations can be effectively prosecuted from the shore station with a small boat.

The following brief summary outlines the other major projects that have so far been initiated or continued in the laboratory. These are described in greater detail in the Report of the Committee on Submarine Configuration and Oceanic Circulation of the National Research Council for the current year.

- (1) Study of the physical hydrology of the water on the continental shelf, Cape Cod to Chesapeake Bay, based on cruises of the Albatross II and of the Atlantis--in charge of H. B. Bigelow.
- (2) Investigation of the phenomena of resuscitation of fishes after freezing--by M. A. Borodin.
- (3) Studies of thermal distribution at the surface of the Northwestern Atlantic based on thermograph records--under the general direction of C. F. Brooks.
- (4) Study of the circulatory and thermal results of the pumping effect of the tides over submarine slopes--by Gardner Emmons.
- (5) Studies of the oceanography of the Grand Banks region and of Davis Strait--by Olav Mosby, oceanographer, International Ice Patrol.
- (6) Studies of the physical chemistry of the sea-water in the vicinity of Woods Hole--by Norris W. Hakestraw.
- (7) Studies on the physical chemistry of respiratory problems of marine animals--by Alfred C. Redfield.
- (8) Studies of the stress exerted by the wind as a propulsive force on the surface of the sea, and of the evaporation from the latter--by C. G. Rossby.
- (9) Chemical studies of submarine sediments with special reference to the phosphorus cycle--by H. R. Seiwel.
- (10) Investigation of the distribution of marine sediments from the shore line out to the continental edge--by Henry C. Stetson.
- (11) Studies in marine bacteriology, with special reference to forms capable of carrying on specific physiological processes--in charge of Selman A. Waksman.
- (12) Study of light-intensity and temperature as factors controlling the rate of swimming of crustacean larvae--by J. H. Welsh.

Woods Hole Oceanographic Institution,
Woods Hole, Massachusetts

OCEANOGRAPHIC WORK AT THE SCRIPPS INSTITUTION OF OCEANOGRAPHY, UNIVERSITY OF CALIFORNIA, LA JOLLA, CALIFORNIA, JULY 1, 1931 TO APRIL 18, 1932

T. Wayland Vaughan

Buildings and equipment

The land of the Institution consists of a 177-acre tract on the sea-front about two miles north of the village of La Jolla. Prior to March 1, 1931, there were on this land one laboratory building, two floors, 75 by 48 feet; a museum-library building, two floors and about a three-quarter basement, 60 by 80 feet; a reinforced concrete pier 1,000 feet long and 20 feet wide; a wooden aquarium 24 by 48 feet with 18 tanks; several service buildings and garages, temporary structures; 24 wooden cottage residences; and a research boat 64 feet long, 18-foot beam, 22 tons net capacity (about 50 tons gross), equipped to work to a depth of about 1,000 fathoms and with a cruising radius of about 1,000 miles.

About March 1, 1931, construction of an additional laboratory building, Ritter Hall, was begun. This building is 100 by 46 feet and has three floors. With the necessary installations it cost \$120,000--\$40,000 contributed by the State, \$40,000 by an anonymous donor, and \$40,000 by the Rockefeller Foundation. Although the building is not very large the installations for oceanographic work represent the most modern type. Provisions within the building are made for work in dynamical oceanography and marine meteorology, a variety of chemical investigations, bacteriology, and physiology. Two rooms are particularly designed for work in special problems of physics, including one room for spectrometry. On the ground floor there are rooms supplied with running salt-water for the culture of marine organisms on a rather large scale, several rooms in a photographic suite, machine-shop and boiler-room, store-room for oceanographic instruments, transformer-vault, and some vacant space which may later be utilized according to the needs of the Institution. On the roof there is a pent-house and outside it there are exposed instruments of several types, the automatic recording-devices of which are in the rooms devoted to physical oceanography and marine meteorology.

In addition to the funds for the new laboratory building, the State Legislature at its last session made a special appropriation of \$40,000 for the improvement and renovation of the Institution a property. This was supplemented by a special contribution of \$2,000, making a total of \$42,000. By means of this fund it has been possible to do many things, one of which was to replace the old salt-water system by a reinforced concrete tank, which holds 80,000 gallons, and to lay both afferent and efferent pipes of pure lead. The tank will supply water to the physiological section of Ritter Hall, the rooms on the lower floor of the old George H. Scripps Laboratory, and the aquarium. The interior of the George H. Scripps Laboratory has been remodeled so as to take care of four of the Institution's projects, namely: Biology of fishes, to which about one-half of the lower floor is devoted; marine sediments, to which about three and a half unit-rooms are assigned; phytoplankton; and foraminifera. Four unassigned rooms may be utilized by visitors. In addition to the \$162,000 for new construction, improvements, and renovation, by careful planning about \$9,500 was made available from the regular funds of the Institution for additional equipment. Therefore, within about 14 months over \$170,000 have been expended in improving the Institution, mostly its facilities for scientific research. In addition to its own scientific staff between 20 and 25 visiting investigators can be accommodated.

From this brief summary statement I think that it will be obvious that the Institution has a very fine set-up. For the kind of investigations in which it is engaged I do not know of any that has better laboratory facilities, but its boat equipment is not adequate for extensive high-seas operations.

Program

The work of the Institution is arranged as a series of interlocking projects, but because of the impossibility of any one person being able to be an expert in all the fields of oceanography a certain amount of sectionizing of the activities is necessary. The different investigations under way at the Institution will, therefore, be outlined

in a sectional way, but it must be borne in mind that there is at the Institution scarcely any investigation which does not require the cooperation of several groups.

Sources of oceanographic data

The arrangements for receiving oceanographic data at the Institution are extensive. Since the first of last July the Institution's boat has made 23 trips, 30 vertical sections, and 450 temperature-records. On water-samples collected by it there have been 450 determinations of salinity; 450 of pH, PO_4 , and SiO_2 ; 200 of NO_2 , NH_3 , and total nitrogen; 300 of CO_2 and carbonates; 100 of boron; and 20 of calcium. Two hundred and fifty plankton-samples were collected. Besides the collections and records made on the boat Scripps the Institution has received water-samples and records of sea-surface temperatures and meteorological data from its own pier and Balboa, Pacific Grove, Huememe, Farallon Islands, Blunts Reef and Columbia River lightships, lighthouse tenders Rose, Lupine, and Sequoia, and from Scotch Cap, Alaska. The Bureau of Lighthouses has rendered valuable service in getting both data and collections. Information has also been received from United States Naval transports, the vessels Guide, Discoverer, and Pioneer of the Coast and Geodetic Survey, the Escuela Naval at Callao, Peru, and the Grace Line ships plying between Valparaiso and Central American ports. The Coast and Geodetic Survey steamer Pioneer has made for the Institution a number of careful vertical sections in the vicinity of the Hawaiian Islands. Besides recording temperatures at successive depths, it collected water-samples and a number of bottom-samples. The Institution has a sea-water thermograph installed on its own pier, the Los Angeles Steamship Company's Calawali, and the United States Lighthouse tender Lupine. Arrangements have been made for the installation of thermographs on the Panama Pacific Company's steamers Pennsylvania, California, and Virginia.

Since July 1, 1931, 3,546 salinity-determinations were made at the Institution; 10,717 records of sea-surface temperatures, 9,498 records of winds, and 5,366 records of air temperatures were received.

Physical oceanography and marine meteorology

The investigations in these fields are in charge of Prof. G. F. McEwen. Ships' reports of sea-surface temperatures and winds from an area of about 50 one-degree quadrangles in the San Francisco section, 1898 to 1931, inclusive, have been utilized to determine monthly averages for selected groups of quadrangles. These results are ready for use with other surface-data in the eastern North Pacific for investigating surface-drift and problems of seasonal weather-forecasting.

The preliminary work of summarizing serial observations at Station 2, five miles west of the Institution's pier, has been completed. Weekly and monthly averages of all shore-station data have been brought up to date, and mimeographed copies are available for distribution. Tabulation of surface-observations at sea according to 30-minute quadrangles and weeks or months has continued as usual, and the data have been plotted on charts.

Dr. McEwen has very nearly completed two papers of a theoretical nature. One presents a theory relating ocean surface-drift to surface-temperatures and solar radiation. This is an extension of his previous work, "Ocean temperatures, their relation to solar radiation and oceanic circulation." He has also obtained a solution of the differential equation of the vertical distribution of temperature and salinity. This solution holds for sufficiently large intervals of time and depth to be of material aid in applying the theory, especially to the problem of determining normal values of temperature and salinity. The results of these theoretical investigations form the basis of two papers, one on surface-drift, the other on upwelling, in preparation for the Fifth Pacific Science Congress.

Professor McEwen prepared the chapter, "A summary of basic principles underlying modern methods of dynamical oceanography," for the volume on oceanography in the series of bulletins, "Physics of the Earth," being published by the National Research Council. He also aided in the translation and preparation for press of a manuscript in German by Dr. Arnold Schumacher on "A survey of present knowledge of oceanic circulation based upon modern physical and chemical observations."

Other work at the Institution is a paper entitled "A sinker method for the determination of specific gravity" by N. W. Cummings, which has been published as No. 5, volume 3, technical series, of the Scripps Institution of Oceanography Bulletin. Mr. Burt Richardson has the following papers either ready or nearly ready for press: A computation of the transmission-coefficient of the Earth's atmosphere from the insolation-records of the eight United States stations; A comparative graphical study of the insolation-records of Pasadena (1926-28) and La Jolla (1928-32) with seven other United States insolation-stations for the same period of time; A description of a photoelectric recording apparatus for measuring foginess; Results of studies at the Scripps Institution of the transmission-coefficient according to depth of sea-water made during the summer of 1931, and the penetration of light in sea-water; A method for computing the amount of evaporation of sea-water from a tank by changes in salinity, with experimental results obtained on board the Scripps, August 13-24, 1928.

Mr. Richardson's work on the penetration of light into sea-water has been one of the important recent investigations at the Institution. A summary of his results is given separately.

The investigations in meteorology at the Institution include, besides Mr. Richardson's meteorologically significant researches, a study by Mr. Horace R. Byers on the problem of air-masses and fronts of the North Pacific Ocean. Dr. McEwen and Dr. A. F. Gorton have continued their efforts to discover a basis for long-range weather-forecasting in the region of southern California. Particular attention was paid to the cyclical characteristics of ocean-temperature and air-temperature records and to the interrelation of temperature and precipitation discovered by Bruckner and elaborated by Schuman. It appears that the ocean-temperature during the "upwelling" period is less significant for forecasting purposes than the general trend of temperature during the eight months preceding the opening of the rainy season.

Chemistry

The investigations in chemistry are in charge of Dr. E. G. Moberg. They have comprised, besides routine determinations of salinity, pH, PO_4 , and SiO_2 , a special investigation of carbon dioxide in sea-water and the seasonal variation of base and carbon dioxide at various depths. From the results of measurements of carbon dioxide, titrable base, and hydrogen-ion concentration, under both natural and experimental conditions, a study of the buffer-mechanism of sea-water was made. This mechanism was concerned with the solubility of calcium carbonate and with a number of chemical equilibria of biological and geological importance. Papers giving the results of these investigations have been prepared by Messrs. Moberg and Greenberg and Miss Esther Allen. Dr. P. L. Kirk of the Division of Biochemistry of the University of California Medical School has adapted a micro-method for the rapid determination of calcium in sea-water. It gives results which are accurate to about one per cent. The method is described in a paper now in press by Kirk and Moberg. Mr. M. W. Harding has made a special investigation of the boron-content of sea-water, and Mr. R. H. Fleming is conducting an investigation of the various types of inorganic and organic nitrogen compounds in the sea. Determination of nitrate, nitrite, ammonia, and total organic nitrogen have been made on water taken at various localities and depths throughout the year. Particular attention is being paid to the several substances which are in solution in sea-water and may serve as plant nutrients.

Biology

General--It should be remarked under this head that an endeavor is made to relate the biological phenomena to the physical and chemical conditions in the sea. Besides such factors as temperature and oceanic circulation, the different substances dissolved in sea-water exert important influences on life in the ocean. The investigations of Mr. Richardson on the depth of penetration of light is obviously of fundamental significance. The biological projects at the Institution exceed seven. They will be briefly outlined in the following notes.

Bacteriological investigations--The bacteriological investigations at the Institution until November, 1931, were carried on by Dr. Gee. His researches embraced three aspects. First, an endeavor was made to obtain information regarding the ocean zones of micro-biological activity. Approximately half of the micro-organisms culti-

vated from ocean-water and bottom-mud were bacteria. Moulds, actinomyces, and yeasts constituted the remainder. The maximum activity was in the mud. The surface zone of activity was found not to exceed about 25 meters. Second, studies were made to ascertain the suitability of culture media. Experiments indicated that the bacteria present in sea-water may exceed by a thousandfold the number that can be obtained by the use of conventional culture-methods. Third, considerable time during the year 1930-31 was devoted to the study of lime deposition in the sea and the role that bacteria might play in the process. Since many marine bacteria are ammonia producers they may be accessory factors in calcium deposition, but it has not been established that ammonifying bacteria are significant agents in precipitating calcium carbonate in the ocean. Attention was paid to the displacement of the calcium equilibrium in sea-water by passing CO₂-free air through the water. By this method a precipitate of aragonite was obtained. This subject will be reverted to in discussing the work on the investigations of marine bottom-deposits of the Institution.

On January 1, 1932, Dr. C. E. ZoBell became the Institution's microbiologist. He is making experiments on different kinds of media in order to ascertain those most effective for the culture of marine bacteria. He is making daily determinations of bacteria in sea-water samples collected from the Institution's pier with reference to factors which may influence their distribution. Temperature, rainfall, chemical composition of the water, solar radiation, oceanic circulation, and biological conditions are being considered. The principal bacteriological investigations, however, are on the role of micro-organisms in the nitrogen cycle in the sea. These include experiments in isolation, determination of relative abundance, and studies of the physiological activities of denitrifiers, nitrogen-fixers, nitrifiers, ammonifiers, and others, using modified soil-bacteriological methods.

Phytoplankton--Prof. W. E. Allen has continued his investigations of photoplankton as in the past. He is now, however, trying to relate his studies of seasonal, geographic, and bathymetric distribution to the results obtained by studies of the depth of penetration of light and the distribution of plant nutrients in the sea-water. The investigation of phytoplankton, therefore, has become a cooperative enterprise between those who are working on the organisms themselves and those who are engaged primarily in the study of the physical and chemical conditions in the sea. Professor Allen and Miss Cupp have completed a large memoir on the plankton-diatoms of the Java Seas which has been sent to Professor Delsman, the Director of the Marine Station in Batavia, for publication. Professor Allen has also reported on a collection of Australian diatoms sent to the Institution by Prof. W. J. Dakin of the University of Sydney. Miss Cupp has for several years been engaged on the study of the ranges of variation in the frustules of the different species of diatoms found in the northeast Pacific. She is considering variation with reference to a number of physical and chemical features of the sea.

Foraminifera--The investigations of foraminifera at the Institution are in charge of Dr. T. W. Vaughan. Besides studies of certain fossil foraminifera, that are of geological significance, there are two other aspects to the investigations. One is the study of the ecologic relations of different foraminiferal faunas and of foraminifera as contributors to marine bottom-deposits. Investigations of this kind overlap the study of marine bottom-deposits. An investigation in which the Institution is concerned is one by Mr. M. L. Natland along a section from Long Beach, California, to Catalina Island. Mr. Natland has already been able to define several different foraminiferal faunas according to ecological conditions. Another aspect of the researches has been the study of the life-history of some of those species of foraminifera which are abundant in the vicinity of the laboratories of the Institution. Mr. E. H. Myers, besides observing the asexual production of individuals, has made for the first time permanent preparations and photo-micrographs of the zoospores, including their conjugation, in the sexual stage of *Tretomphalus bulloides*. He has substantiated a claim of long standing by observing all stages in the metamorphosis of this species from a bottom-dwelling form into a pelagic form. He maintained successive cultures for eighteen months.

Fishes--Almost from the foundation of the Institution occasional studies have been concerned with one or another phase of fish biology. Within the past few years, this field of investigation has been given the status of a definite section of the Institution's work, under charge of Dr. F. B. Sumner, and a portion of George H. Scripps

Laboratory has recently been remodeled and equipped for this purpose. The studies thus far undertaken or contemplated relate chiefly to the physiology or ecology of these organisms, with special reference to the effects of changes in one or another environmental factor. The life-histories of certain local fishes have also received attention.

Mr. N. A. Wells is at present engaged in comparative studies of oxygen-consumption in marine fishes, as affected by age, sex, species, temperature of water, and perhaps other factors. These studies involve quantitative determinations of oxygen in samples of water taken from containers in which the fishes are kept under controlled conditions of temperature and rate of water-flow.

For about two years Dr. Sumner, in collaboration with N. A. Wells, has been making experiments, as well as microscopic studies, upon pigmentary changes in the guppy (*Lebistes reticulatus*) when reared upon various backgrounds. This investigation involves the preparation of histological sections and the taking of microphotographs of these and of areas of the integument of entire fishes, both living and dead. Marked changes, not only in the visible shade, but in the actual amount of black pigment (melanin), have been determined.

Dr. Sumner and Dr. Fox have commenced an investigation of the yellow and orange colored carotinoid (lipochrome) pigments of *Fundulus* and other marine fishes, with particular reference to possible quantitative and qualitative differences due to environmental causes.

Mr. P. S. Barnhart has recently published a paper entitled "Notes on the habits, eggs, and young of some fishes of southern California," in which he records some of his numerous observations, made during his long connection with the Institution's staff.

Physiology of marine invertebrates--There has been added to the Institution a Section of Physiology for the study of the interrelationships between marine invertebrates and their environment. Dr. D. L. Fox was placed in charge of the Section, and assumed his duties at the Institution on September 1, 1931. During the latter part of December, 1931, and the first half of January, 1932, Dr. Fox conducted experiments at Berkeley in collaboration with Dr. H. F. Blum of the Division of Physiology of the University of California Medical School on light-response in the brine flagellate *Dunaliella salina* with respect to wave-lengths. Dr. Fox's work in conjunction with Dr. F. B. Sumner has already been mentioned. Dr. Fox has also initiated studies on the oxygen-deprivation tolerance, and more especially on the desiccation tolerance of certain marine sipunculid worms. Indications are that these animals, which provide hardy, interesting material for laboratory study and culture, tolerate a great oxygen-deficit for several days if kept in sea-water, and succumb to desiccation at a rather clearly definite limit which lies, on an average, between 40 and 50 per cent loss of total water. It is expected that studies of salt-concentration, within the organisms and in the surrounding medium, will be made as parallels to the water-content investigation.

Miscellaneous--Prof. W. R. Coe of Yale University conducted studies of the seasonal attachment and rate of growth of sedentary marine invertebrates and algae at the Scripps Institution pier, and has published his results in the Scripps Institution Bulletin technical series (v. 3, No. 3, 1932). He has also published in the same scientific series a report on gonad development and sexual cycles in the California oyster (*Ostrea lurida*).

Dr. W. W. Lepeschkin, while a visitor at the Institution in 1930, conducted investigations upon some influences of light and poisons on marine copepods. The results of his work are published in the Institution's bulletin (tech. ser., v. 3, No. 2, 1931). He is of the opinion that exposure to direct rays of sunlight decreases the resistance of certain copepods to the toxic action of such a poison as mercuric chloride, and that short exposures to the ultraviolet portion of the solar spectrum may increase the resistance of the organisms toward the poison.

Considerable work has been done on corals at the Institution during the past twelve months. Mr. John W. Wells, a Storrow Fellow in Geology, spent three months at

the Institution; and then transferred to the United States National Museum in Washington. Reports on corals have been made to Rev. Father Gherri, S.J., Zi-ka-wei Observatory, Shanghai, on a collection from Pratas Shoals between the Philippines and Formosa; on a rather large collection from the Japanese islands in the Pacific, the latter collection being of special interest because it was largely made by the Emperor of Japan; and on a collection made in the Pearl Islands, Midway Group, by Dr. P. S. Galtsoff. T. W. Vaughan, in association with J. W. Wells, is preparing for the *Handbuch der Palaeoecologie*, being edited by Professor Schindewolf in Berlin, the section on hexacorals. This work will comprise reviews of all hexacorall genera and discussions of such topics as morphology, development, physiology, and ecology of the organisms.

Marine sediments

The investigations on marine sediments have been organized by Dr. T. W. Vaughan in cooperation with several others, mentioned below. One of the principal projects has been the continuation and extension of the investigation of calcium-carbonate sediments begun by him in Florida in 1907, and prosecuted by him in cooperation between the Department of Marine Biology, Carnegie Institution of Washington, and the United States Geological Survey until he transferred his residence to California in January, 1924. The investigations as they have been developed have comprised three methods of attack, the first of which is a study of the carbon-dioxide and calcium relations in sea-water. This work has been done partly by those associated with the chemical investigations at the Institution (particularly by Dr. E. G. Moberg, Dr. D. M. Greenberg, Dr. P. L. Kirk, and Miss Esther Allen), and it has been done partly by Dr. Gee in connection with his bacteriological investigations. It is not practicable in a report such as this to give even a synopsis of the results. It can merely be mentioned that, besides a short abstract entitled "The relation of the buffer-mechanism of sea-water to the solubility of calcium carbonate," by D. M. Greenberg and E. G. Moberg, contained in the report of the Committee on Sedimentation of the National Research Council for this year, at least three other papers by Greenberg, Moberg, Esther Allen, and P. L. Kirk are now in press. The following two sentences may be quoted from the abstract above mentioned:

"This is of significance in the solubility of calcium carbonate since it shows that when from gross analytical figures there is indicated an apparent supersaturation, there may actually be a large under-saturation. Moreover, a knowledge of the activity-coefficients will make it possible to calculate the true state of affairs, since on the basis of thermodynamic theory, the true solubility product, that is, the product in terms of the activity of the ion-components, is a true constant, independent of the chemical state of the solution. The present study represents a step toward the working out of the whole problem."

A second method of attack has been, in collaboration with the Carnegie Institution of Washington, a renewal of the attempt to evaluate bacteria as possible agents in the precipitation of calcium carbonate in the ocean. Dr. Haldane Gee has contributed an abstract of an investigation by him entitled *Characteristics of bacteria from the Florida Keys*, to the report of the Committee on Sedimentation for this year. Besides this abstract Gee has published or has in press between ten and a dozen other papers. A few of his conclusions may be quoted. With reference to the bacteria he says:

"The physiological behavior of the individuals was, however, similar in two important aspects. Almost all the organisms produce ammonia, and none has yet been found to produce carbon dioxide. Consequently the bacteria studied thus far are factors aiding the precipitation of calcium carbonate from the sea-water."

Gee's work was confined to an investigation of the aerobic organisms, but, as he says, the anaerobes should also be investigated. Gee undertook at Tortugas an experiment in precipitating calcium carbonate by passing CO₂-free air through water at a temperature of 30° C and at an initial salinity of 36.1 per mille, from which biological activity had been eliminated. The artificial precipitate was composed of aragonite needles and rosettes, but precipitation did not take place until a salinity of about 39 per mille

and a pH of about 9.3 had been attained, a pH beyond any known in normal sea-water. Subsequent to Gee's experiments Messrs. R. R. Revelle and R. H. Fleming have had similar experiments in the chemical laboratory at the Scripps Institution by reducing the water to a salinity of 37.8 per mille and conducting the experiment at a temperature of 30° C. They obtained a precipitate similar to the one obtained by Gee, except that the aragonite needles and the rosettes were larger than those in his precipitate, and in addition to them there were spherulites, which were actually more numerous than needles and rosettes. Again, however, precipitation did not take place until a pH above 9.0 had been attained. Immediately after the precipitation the pH of the water dropped to about 8.9, which was still above normal. Additional laboratory experiments are contemplated to determine the effect of increase of salinity on precipitation.

The third attack on the problem has been the detailed study of numerous bottom-samples according to more or less established procedure, that is, mechanical analyses, chemical analyses, and descriptions of the separates. Mr. E. M. Thorp, who has already published a paper entitled "Descriptions of some deep-sea bottom-samples from the western North Atlantic and the Caribbean Sea" (Scripps Inst. Oceanog. Bull., v. 3, No. 1, 1931), has devoted many months to the description of something over two hundred samples collected by T. W. Vaughan in Florida and the Bahamas. Vaughan has already described a number of these samples and has given much information on sizing, chemical composition, and organisms, and one set of samples from the vicinity of Coconut Point, Andros Island, was described in great detail by M. I. Goldman. Description of the entire collection has not yet been finished, but it is approaching completion. The results of the descriptive work will obviously be correlated with the investigations of chemical conditions in the sea, the possible role of bacteria, and other organic and inorganic processes. It is scarcely to be expected that the entire problem will be solved, but important advance has certainly been made in understanding the complex phenomena. One of Mr. Thorp's findings in both the bottom-deposits and the residue of the Bahamian oolites, after treating the material with 0.2 N hydrochloric acid, is that there is an appreciable amount, but less than one per cent, of mineral fragments of volcanic origin.

In connection with these investigations, it may be mentioned that T. W. Vaughan, in association with E. M. Thorp, is making a compilation for an account of the classification and the nomenclature of calcium-carbonate sediments.

Another project under way at the Scripps Institution is the study of the deep-sea sediments of the Pacific Ocean. Besides the large number of samples collected by the Coast and Geodetic Survey vessels, especially between Panama, Canal Zone, and the latitude of San Diego, the Institution has received all of the samples collected by the Carnegie during its work in the Pacific. The mechanical analyses of the samples were finished about a year ago, and the chemical analyses, made by Sharp-Schurtz Company, were completed some months later. Mr. Roger R. Revelle is now engaged in describing the different samples. He will assemble and correlate all the data on the samples. Subsequent to the receipt of the Carnegie samples the Coast and Geodetic Survey Pioneer has made an additional collection of deep-sea samples in the vicinity of the Hawaiian Islands.

The Institution has also received from the Pacific considerable additional collections of shallow-water calcium-carbonate deposits which are more or less associated with coral reefs. One of the collections was made by Dr. P. S. Galtsoff on Pearl Reef, Midway Islands, of the Hawaiian group.

Conclusion

With reference to the scientific program of the Institution it will be remarked that, notwithstanding the rather large number of research projects, there is scarcely one which is isolated from other researches at the Institution. The investigation of marine bottom-deposits is a good illustration of how in one group of phenomena all of the different aspects of the ocean are concerned. In order to understand any marine bottom-deposit we must consider the physical oceanography, chemistry, with particular emphasis on physical chemistry, and the organisms. An endeavor has been made to develop a unified program.

Scripps Institution of Oceanography,
La Jolla, California.

CONTRIBUTIONS OF THE UNITED STATES HYDROGRAPHIC OFFICE TO OCEANOGRAPHY

A. B. McManus

The participation of the United States Hydrographic Office in the field of oceanography during the year of 1931 and up to the present date may be briefly summarized as follows:

United States Naval surveys--Surveying of the high seas and of foreign coasts has been carried on by three surveying vessels under the cognizance of the Hydrographic Office. The U.S.S. Nokomis, operating on the north coast of Cuba, extended its hydrographic surveys from the previous season's work from about longitude 76° 50' west, eastward to Baracoa. This survey when extended to Cape Maysi will complete the hydrographic surveys of the entire coast of Cuba.

The U.S.S. Hannibal has completed the hydrographic surveys of the Venezuela area of the Gulf of Paria, covering approximately 1,400 square miles. The Gulf of Paria, situated between the mainland of Venezuela and the Island of Trinidad, forms a connection between the Caribbean Sea and the Atlantic Ocean. The British surveys of the coast of Trinidad extend about half way across the Gulf. The surveys recently completed by the U.S.S. Hannibal cover the remaining or western portion of the Gulf of Paria, an extensive area heretofore unsurveyed.

The U.S.S. Fulton has continued surveying operations in the Gulf of Panama extending the hydrographic survey of the Gulf which was begun by the U.S.S. Niagara in 1928. This survey has now been completed over the portion of the Gulf of Panama extending eastward from longitude 79° 15' west to Pt. Arditá at the extreme southeastern end of the Gulf and including the Perlas Islands and San Miguel Bay. This survey is now being continued by the U.S.S. Fulton and U.S.S. Hannibal.

Aerial photography has been employed extensively in connection with all the surveys for delineation of shore lines and other topographic features.

Charts from United States Naval surveys--The following is a list of new Hydrographic Office charts based on original United States Naval surveys published within the past year:

- 307 - Habana Harbor, Cuba
- 1882 - Puerto Gibara, West Indies, north coast of Cuba
- 1883 - Puerto de Nuevitas, Cuba
- 2209 - Bahía Honda, Cuba
- 2210 - Puerto Cabanas, north coast of Cuba
- 2622 - Cayo Jutías to Puerto Cabanas, north coast of Cuba
- 2623 - Puerto Cabanas to Puerto Matanzas, north coast of Cuba
- 2627 - Cayo Paredon Grande to Punta Maternillos, north coast of Cuba
- 5159 - Puerto Mariel, Cuba
- 5167 - Plans on the north coast of Cuba

Sonic soundings obtained by United States Naval vessels--The following is a tabulated list of soundings taken by United States Naval vessels from January 1, 1931 to December 31, 1931:

- U.S.S. Ramapo - 1,346 sonic soundings taken en route Manila, P.I., to Guam, M.I., Pearl Harbor, T.H., and Mare I., Calif., crossing 18° 06' N in 136° E, 21° 05' N in 170° W, 31° 35' N in 140° W, and 37° 30' N in 123° 40' W.
- U.S.S. Nevada - 4 soundings on shoal area off California coast in 32° 37' 30" N and 119° 33' 30" W.
- U.S.S. Houston - Line of 177 sonic soundings en route Balboa, Canal Zone, to Honolulu, T.H., crossing 14° 19' N in 106° 38' W, 20° 04' N in 135° 09' W, and 21° 15' N in 155° 05' W.

- U.S.S. Colorado - 145 sonic soundings taken on voyage from San Pedro, Calif., to Balboa, Canal Zone, crossing $28^{\circ} 58' N$ in $116^{\circ} 31' W$, $15^{\circ} 53' 30'' N$ in $106^{\circ} 26' W$, and $4^{\circ} 30' 30'' N$ in $91^{\circ} 58' W$.
- U.S.S. New Mexico - Line of 135 sonic soundings taken in North Pacific crossing $28^{\circ} 54' N$ in $118^{\circ} 28' W$, $15^{\circ} 41' N$ in $106^{\circ} 18' W$, and $3^{\circ} 25' N$ in $89^{\circ} 59' W$.
- U.S.S. Nevada - 41 sonic soundings in North Pacific crossing $29^{\circ} 01' 30'' N$ in $116^{\circ} 27' W$, $23^{\circ} 55' 50'' N$ in $113^{\circ} 09' W$, and $3^{\circ} 33' N$ in $94^{\circ} 26' W$.
- U.S.S. Maryland - Line of 228 soundings while cruising in North Pacific crossing $29^{\circ} 12' N$ in $116^{\circ} 33' 30'' W$, $15^{\circ} 48' 00'' N$ in $106^{\circ} 16' 15'' W$, $1^{\circ} 48' N$ in $94^{\circ} 06' 30'' W$, $10^{\circ} 12' 45'' N$ in $86^{\circ} 07' 45'' W$, and $7^{\circ} 20' N$ in $79^{\circ} 54' W$.
- U.S.S. California - Line of 137 sonic soundings in North Pacific crossing $28^{\circ} 51' N$ in $118^{\circ} 21' W$, $15^{\circ} 42' 20'' N$ in $106^{\circ} 15' W$, $1^{\circ} 58' N$ in $93^{\circ} 08' W$, and $5^{\circ} 35' N$ in $84^{\circ} 36' W$.
- U.S.S. Idaho - 266 sonic soundings in North Pacific crossing $29^{\circ} 03' N$ in $116^{\circ} 30' W$, $15^{\circ} 58' N$ in $106^{\circ} 30' W$, $2^{\circ} 13' N$ in $92^{\circ} 19' W$, and $4^{\circ} 11' N$ in $88^{\circ} 11' W$.
- U.S.S. Ramapo - 414 sonic soundings en route San Pedro, Calif., to Pearl Harbor, T.H., crossing $33^{\circ} 20' 30'' N$ in $120^{\circ} 18' W$, $30^{\circ} 25' N$ in $134^{\circ} 18' W$, and $21^{\circ} 14' N$ in $157^{\circ} 39' W$.
- U.S.S. Ramapo - 373 sonic soundings on return trip Pearl Harbor, T.H., to San Pedro, Calif., crossing $21^{\circ} 17' N$ in $157^{\circ} 30' W$, $28^{\circ} 41' 30'' N$ in $141^{\circ} 13' W$, and $33^{\circ} 27' 30'' N$ in $119^{\circ} 51' W$.
- U.S.S. Houston - 209 sonic soundings, during passage from Honolulu, T.H., to Guam, M.I., crossing $21^{\circ} 15' N$ in $159^{\circ} 30' W$, $20^{\circ} 31' N$ in $179^{\circ} 43' E$, and $13^{\circ} 36' N$ in $144^{\circ} 44' E$.
- U.S.S. Houston - 71 sonic soundings, during passage from Guam, M.I., to Manila, P.I., crossing $13^{\circ} 27' N$ in $144^{\circ} 31' E$, $13^{\circ} 08' N$ in $134^{\circ} 25' E$, and $12^{\circ} 51' N$ in $125^{\circ} 08' E$.
- U.S.S. Arizona - 22 soundings by fathometer and sounding-machine en route Hampton Roads, Va., to Ponce, P.R., over Navidad Bank in $20^{\circ} N$ and $68^{\circ} 50' W$.
- U.S.S. California - 64 soundings taken in North Pacific crossing $6^{\circ} 39' N$ in $79^{\circ} 47' W$, $15^{\circ} 19' 40'' N$ in $99^{\circ} 33' 40'' W$, and $33^{\circ} 12' 30'' N$ in $116^{\circ} 59' W$.
- U.S.S. West Virginia - 76 sonic soundings taken in North Pacific crossing $8^{\circ} 21' N$ in $79^{\circ} 36' W$, $22^{\circ} 44' N$ in $110^{\circ} 29' W$, and $29^{\circ} 55' N$ in $116^{\circ} 45' W$.
- U.S.S. Idaho - 138 soundings taken in North Pacific with the Fessenden system, crossing $7^{\circ} 52' N$ in $79^{\circ} 56' W$, $19^{\circ} 34' N$ in $106^{\circ} 29' W$, and $33^{\circ} 09' N$ in $117^{\circ} 36' W$.
- U.S.S. Ramapo - 323 sonic soundings en route San Pedro, Calif., to Pearl Harbor, T.H., crossing $33^{\circ} 32' 45'' N$ in $118^{\circ} 55' 30'' W$, $27^{\circ} 12' N$ in $143^{\circ} 26' 15'' W$, and $22^{\circ} 46' 30'' N$ in $154^{\circ} 21' 30'' W$.
- U.S.S. Colorado - 67 sonic soundings on voyage from Balboa, Canal Zone, to San Pedro, Calif., crossing $8^{\circ} 12' 30'' N$ in $79^{\circ} 36' 30'' W$, $17^{\circ} 10' N$ in $102^{\circ} 49' 30'' W$, and $32^{\circ} 46' N$ in $117^{\circ} 30' W$.
- U.S.S. Nevada - 73 soundings by fathometer while making passage from Panama, Canal Zone, to Los Angeles, Calif., crossing $7^{\circ} 06' N$ in $81^{\circ} 06' W$, $18^{\circ} 35' N$ in $104^{\circ} 15' W$, and $32^{\circ} 46' 30'' N$ in $117^{\circ} 48' 30'' W$.
- U.S.S. Fulton - While searching for "Guardian Bank" obtained 1,754 sonic soundings crossing $8^{\circ} 45' N$ in $86^{\circ} 45' W$, and $9^{\circ} 50' N$ in $88^{\circ} 15' W$.

U.S.S. Henderson - 40 sonic soundings in North Pacific around $36^{\circ} 08' 45''$ N and $120^{\circ} 56' 10''$ E.

U.S.S. Arizona - 9 fathometer soundings off Watling Island at $24^{\circ} 06' 30''$ N in $74^{\circ} 22' 10''$ W.

U.S.S. Ramapo - 1114 sonic soundings en route San Pedro, Calif., to Manila, P.I., crossing $34^{\circ} 13' 13''$ N in $122^{\circ} 12' 12''$ W, $36^{\circ} 13' 13''$ N in $158^{\circ} 09' 29''$ W, $29^{\circ} 22' 13''$ N in $173^{\circ} 17' 13''$ E, and $13^{\circ} 30' 13''$ N in $125^{\circ} 49' 13''$ E.

U.S.S. Ramapo - 596 sonic soundings en route Manila, P.I., to San Pedro, Calif., crossing $16^{\circ} 33' 13''$ N in $119^{\circ} 41' 13''$ E, $41^{\circ} 56' 13''$ N in $160^{\circ} 06' 30''$ E, $44^{\circ} 54' 13''$ N in $167^{\circ} 02' 13''$ W, and $42^{\circ} 14' 13''$ N in $142^{\circ} 05' 30''$ W.

U.S.S. Henderson - 14 fathometer- and lead-soundings off Watling Island in $24^{\circ} 06' 30''$ N and $74^{\circ} 22' 10''$ W.

U.S.S. West Virginia - 13 sonic soundings in North Pacific in $38^{\circ} 09' 13''$ N and $123^{\circ} 42' 13''$ W.

U.S.S. Hannibal - Line of 328 sonic soundings en route Philadelphia, Pa., to Guantanamo, Cuba, crossing $37^{\circ} 29' 13''$ N in $74^{\circ} 11' 13''$ W, $30^{\circ} 33' 30''$ N in $74^{\circ} 17' 30''$ W, $27^{\circ} 31' 30''$ N in $74^{\circ} 17' 30''$ W, $23^{\circ} 14' 45''$ N in $74^{\circ} 27' 45''$ W, and $19^{\circ} 51' 35''$ N in $75^{\circ} 07' 30''$ W.

U.S.S. Ramapo - 972 sonic soundings en route San Pedro, Calif., to Manila, P.I., crossing $34^{\circ} 57' 13''$ N in $124^{\circ} 39' 13''$ W, $37^{\circ} 21' 30''$ N in $149^{\circ} 15' 13''$ W, $32^{\circ} 54' 15''$ N in $179^{\circ} 13' 45''$ E, and $20^{\circ} 10' 13''$ N in $137^{\circ} 23' 13''$ E.

U.S.S. West Virginia - 34 sonic soundings while cruising over "Guardian Bank" from $7^{\circ} 43' 13''$ N and $83^{\circ} 56' 13''$ W, and $8^{\circ} 46' 13''$ N and $87^{\circ} 28' 13''$ W.

U.S.S. Hannibal - 807 sonic soundings while searching for reported shoal off Cape San Antonio, Cuba, in area contiguous to $22^{\circ} 25' 13''$ N and $85^{\circ} 10' 13''$ W.

U.S.S. Hannibal - Line of 202 sonic soundings en route Guantanamo, Cuba, to Port of Spain, Trinidad, crossing $19^{\circ} 50' 13''$ N in $76^{\circ} 09' 15''$ W, $16^{\circ} 40' 45''$ N in $71^{\circ} 46' 13''$ W, $14^{\circ} 31' 30''$ N in $67^{\circ} 04' 30''$ W, and $11^{\circ} 26' 30''$ N in $62^{\circ} 06' 45''$ W.

U.S.S. Hannibal - 138 sonic soundings while investigating shoal area off Watling Island, vicinity of $24^{\circ} 06' 30''$ N and $74^{\circ} 22' 10''$ W.

Between October 31, 1929 and January 20, 1931, the U.S.S. Ramapo crossed the North Pacific Ocean ten times, recording about 8,600 sonic soundings mostly in unsounded areas. These soundings were taken at an average time-interval of 30 minutes or approximately four to five miles apart, and 830 of them were obtained at positions determined from astronomical observations or from charted landmarks.

Of the total number of soundings recorded by the Ramapo on these ten voyages, 3,693 have been listed and printed in Hydrographic Office Publication No. 210a, published January 20, 1932.

In addition to these ten lines of soundings the Ramapo has run ten more across the North Pacific obtaining sonic soundings, the results of which have not as yet been prepared for publication.

Current-charts--On the reverse sides of the Pilot Charts of the North Atlantic Ocean for July and October 1931, and January and April 1932, there appeared revised presentations of the Current-chart of the North Atlantic Ocean for January, April, July, and October, covering the track of low-powered steamers between the Straits of Florida and the English Channel and the Straits of Gibraltar. These charts were originally published beginning with the year 1926 and republished several times since. The revised charts give, in addition to the data heretofore shown, the traverse resultant-drifts in the one-degree quadrangles.

The Pilot Charts of the North Pacific Ocean for March and June 1932, respectively, carry on their reverse side current-charts covering the greater portion of the North Pacific Ocean for the quarters, March, April, and May, and June, July, and August. Heretofore the data contained on these charts have been published in two sections and on the reverse sides of separate Pilot Charts. The data as now presented on these new charts enable the navigator to have more readily at his disposal the necessary information regarding the average current-conditions expected on a trans-Pacific passage at these periods of the year.

A current-chart showing currents reported observed in the western portion of the North Pacific Ocean during the quarter September, October, and November, from 1904-24, was printed on the reverse side of the Pilot Chart of the North Pacific Ocean for September 1931. With the presentation of the currents observed in the western North Pacific Ocean, during the months of December, January, and February, from 1904-24, which has been made ready for early future publication, the purpose of the Hydrographic Office to furnish averaged current-data relating to certain areas of the North Pacific Ocean, where oceanic conditions lend themselves to the procedure of estimating the value of individual currents reported observed, will be accomplished.

Oceanic temperatures--The summarization of the observations by mariners of the temperature of the surface-waters of the North Pacific Ocean during 1904-24 is now nearing the stage of publication in the form of monthly charts showing the number of observations and the average temperature for each month in one-degree quadrangles.

Bartlett Deep--Pursuant to the plans for conducting special examinations of deeps by United States Naval vessels when circumstances warrant, the U.S. Submarine S-48 and U.S.S. Chewink while pursuing a route between the western end of Jamaica and the western end of Cuba, in cooperation with the International Scientific Expedition to the West Indies, have developed a profile across the Deep just eastward of Grand Cayman Island by means of the soundings which show the existence, near the northern side, of a depth of nearly 4,000 fathoms.

Guardian Bank--Since the investigation of the Guardian Bank area made a year ago by the U.S.S. Fulton, several other naval vessels have taken soundings in that area. It is hoped that the results of future examinations of the Guardian Bank region supported by the evidences obtained by running surveys recently made by naval vessels, will serve to satisfactorily delineate the extent and configuration of Guardian Bank.

International Scientific Expedition to the West Indies--In cooperating with the International Scientific Expedition sponsored by Princeton University, the U.S. Submarine S-48 and the U.S.S. Chewink were assigned for the purpose by the Navy Department at the instance of the Hydrographic Office. Observations for the determination of the intensity of gravity were made at 52 stations in the channels running through the Bahama Archipelago and in the bordering tracts of the ocean, including the waters surrounding Cuba and Jamaica, and also in delineating profiles of the conformation of the bottom of the sea along these routes, aggregating 4,000 miles in length, which lead from one to another of the selected gravity-stations by means of closely-spaced soundings of the depth throughout these waters.

Dr. F. A. Vening Meinesz of the Netherlands Geodetic Commission, distinguished for his achievements in gravity-observations in the U.S. Submarine S-21 in the West Indies Naval Expedition of 1928 and in the submarines of the Netherlands Navy in world-encircling expeditions, joined this Expedition, bringing with him the pendulum-apparatus of his invention for the observing of the intensity of gravity.

Navigators' Sailing Directions or Pilots--The Hydrographic Office has continued to revise and issue, at the rate of some seven volumes per year, modernized editions of the navigators' handbooks known as Sailing Directions, 56 in number, which supplement the charts with information on oceanic routes, inshore navigation, and ports. This information is compiled after an examination of hydrographic survey reports, current issues of original foreign Sailing Directions and charts, and the reports of co-operating navigators and field agencies of the United States Government. Though written to meet the practical needs of overseas merchant and naval vessels of the United States, these books occupy a unique place among geographic reference-works in that they present a connected description of the coast-lines, ports, and harbors of the world.

Treatment of oceanographic data received--In carrying out the work begun by Maury, but by methods more in keeping with the spirit of the age, some 200,000 individual reports relating to oceanography received yearly are now being punched on cards by the use of an automatic punching-device, so that information obtained may not lie idle for months if not for years, and in order to more expeditiously and economically handle the data, particularly those data concerning currents and temperatures of the sea, and sea and swell.

Conclusions--Many facts of importance to the safety of navigation and of special interest to the scientist have resulted from the work of the Hydrographic Office in carrying out the obligations imposed upon it by law, and the desires of maritime and other interests.

There is every expectation that the important accessions acquired relating to soundings, temperatures, and currents with their concomitant data will add much to the knowledge of the depths and circulation of the waters, particularly of the North Pacific and North Atlantic oceans.

Mention may be made of the empiric substantiation of the elliptical current-whirl off the west coast of Central America with its long axis lying between 3° and 6° north latitude and 83° and 100° west longitude.

The fact that the Hydrographic Office is the only branch of the United States Government which is not restricted to survey and research in the navigable tidal waters of the United States, its possessions, and dependencies, or certain specified waters of the globe, serves as a continuing stimulation to greater service.

U. S. Hydrographic Office,
Washington, D. C.

OCEANOGRAPHIC WORK OF THE COAST AND GEODETIC SURVEY DURING THE PAST YEAR

Frank S. Borden

Oceanographic activities of the Coast and Geodetic Survey might well be classified with the by-products of those operations which the Bureau is charged by law to perform.

In serving the mariner, the Bureau measures the depths of the coastal waters and studies their circulation. In determining the position of offshore soundings with the accuracy demanded by the present-day navigator, exact knowledge must be had of the velocity of sound in sea-water. As this varies considerably with the temperature and appreciably with the salinity, many values of these properties are obtained. In determining exact profiles of the bottom by echo-sounding and in coordinating these by radio-acoustic ranging accurate delineations of offshore submarine features are made available.

The principal project on the Atlantic Coast during the past year was the continuation of the survey of Georges Bank undertaken in 1930 at the request of both shipping and fishing interests for more detailed charts of that region. Four of the Bureau's vessels, the Hydrographer, Oceanographer, Lydonia, and Gilbert, participated in this work.

The most difficult problem involved in this survey was that of controlling the position of the sounding-lines. The region is enveloped in fog a large percentage of the time, while tidal currents are exceptionally strong. Moreover, the uneven nature of the bottom over the shallower portions of the bank made it necessary to space the sounding-lines much closer than is ordinarily required in obtaining a true configuration of the bottom.

The basic control for the 1931 season consisted of a scheme of radio-acoustic triangulation, 70 miles in length, along the axis of the Bank (Fig. 1). The stations in the scheme consisted of buoys planted by the field parties at intervals of from 10 to 15 miles, as shown. The position of one buoy--Station Able at the eastern end of

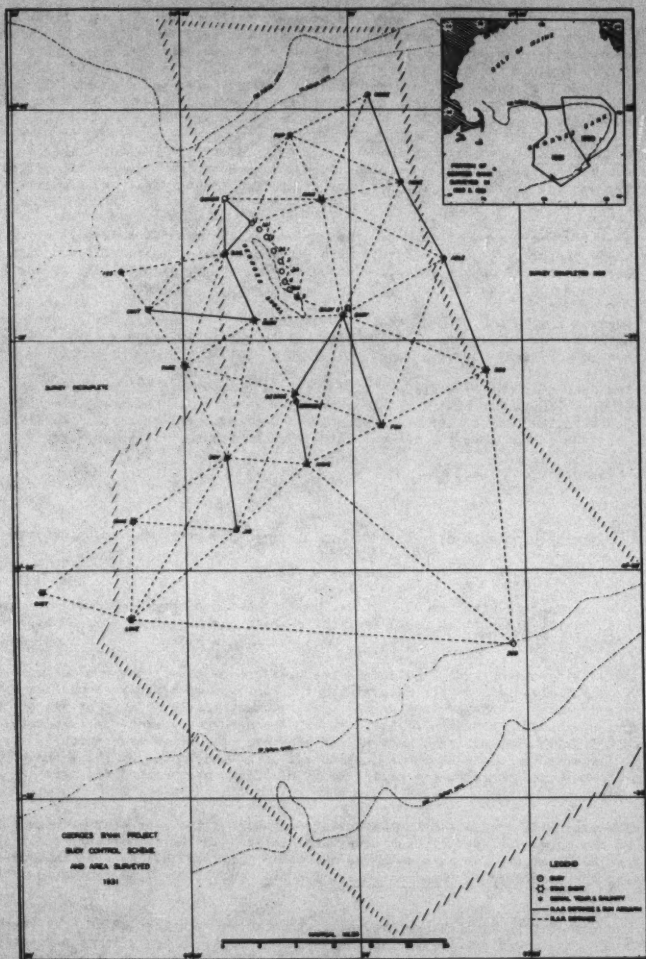


Fig. 1

the scheme--had been determined astronomically from a large number of observations made during the previous season. The lengths of all the lines shown were obtained by radio-acoustic methods. The scheme was oriented by Sun azimuths observed at frequent intervals between conveniently located buoys. These are indicated by the solid lines. The quadrilaterals in the scheme and the scheme as a whole were then adjusted and the geographical position of each of the 23 buoys computed.

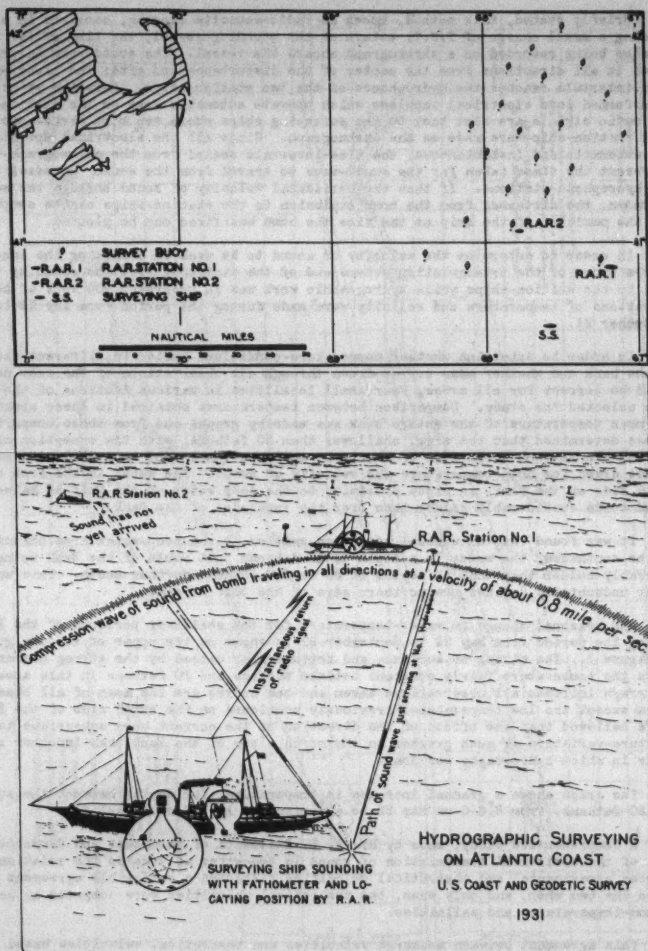


Fig. 2

Having determined the positions of the control buoys, the ships *Lydonia* and *Gilbert* then anchored at any two of the buoys, convenient to the area to be surveyed, and served as hydrophone-stations (Fig. 2). The ships *Hydrographer* and *Oceanographer* ran the sounding-lines, the positions on which were rigidly fixed by the frequent determination of radio-acoustic distances simultaneously obtained from the two hydrophone-stations.

Briefly stated, this method, known as radio-acoustic ranging, consists in exploding a small charge of T.N.T. astern of the sounding vessel, the time of the explosion being recorded on a chronograph aboard the vessel. The sound-wave is propagated in all directions from the center of the disturbance and after the lapse of certain intervals reaches the hydrophones of the two station-ships. Here the waves are transformed into electrical impulses which operate automatic keys on the station-ships and radio signals are sent back to the surveying ships where two more marks--one from each station-ship--are made on the chronograph. Since all the electrical operations are automatic and instantaneous, the time-intervals scaled from the chronograph-tape represent the times taken for the sound-wave to travel from the sound-g vessel to the two hydrophone-stations. If then the horizontal velocity of sound through the water is known, the distances from the bomb explosion to the station-ships can be computed and the position of the ship at the time the bomb was fired can be plotted.

In order to determine the velocity of sound to be used in computing the lengths of the lines of the triangulation-scheme and of the distances from the sounding vessels to the station-ships while hydrographic work was in progress, 300 sets of observations of temperature and salinity were made during the period from May 22 to September 21.

In order to determine whether temperature-conditions varied in different sections of the bank and whether mean curves drawn through all observations of the same depth would be correct for all areas, four small localities in various sections of the Bank were selected for study. Comparison between temperatures obtained in these areas and the mean temperature of the entire bank was made by graphs and from these comparisons it was determined that the area, shallower than 30 fathoms, with the exception of the area on the extreme north side of the Bank, could be considered as a whole and mean curves drawn for both temperature and velocity of sound. The water in the area on the north side of the Bank, in close proximity to the deep water of the Gulf of Maine, was found to be considerably colder than over the remainder of the Bank.

It was found that an unusual condition existed in the deep-water area extending to the southward, the water in a depth of 40 fathoms just south of the Bank being considerably colder than that in depths of 50 to 200 fathoms further south. This warmer water undoubtedly defines the northern edge of the Gulf Stream.

The seasonal change in water-temperature for the shallower portions of the Bank during the period from May 22 to September 21 is shown on the upper of the two graphs in Figure 3. The mixing of surface- and bottom-water caused by the strong currents keeps the temperature fairly constant between surface and 20 fathoms in this area. The graph includes all observations taken and the curves are the mean of all observations except the low temperatures previously mentioned on the north side of the Bank. It is believed that the effect of the direction of the current upon subsurface temperature-variation is much greater on the north slope of the Bank than in other sections in which hydrography was done.

The graph shows a gradual increase in temperature, for depths between the surface and 20 fathoms, from 8.8 C on May 22 to a maximum of 17.5 C on August 8.

A comprehensive study, made by Mr. A. L. Shalowitz of the Coast and Geodetic Survey, of the horizontal transmission of sound in sea-water as regards the relationship between experimental and theoretical velocities disclosed a remarkable agreement between the two when, and only when, the theoretical velocities were computed by using bottom-temperatures and salinities.

This agreement between measured velocities and theoretical velocities based on bottom-temperatures would seem to indicate that the peak of the energy reaching the hydrophones comes not by the shorter straight-line path where the velocity is greater, but by way of the more circuitous path of the bottom-layers of water where the velocity is actually less. It has been suggested that it is primarily a question of temperature; that a given amount of energy will travel farther in cold water than in warm water and though the velocity of sound is greater near the surface the energy is used up quicker and over long distances fails to reach the hydrophone. Hence, the only record we get is of the energy that has come by way of the bottom-layers.

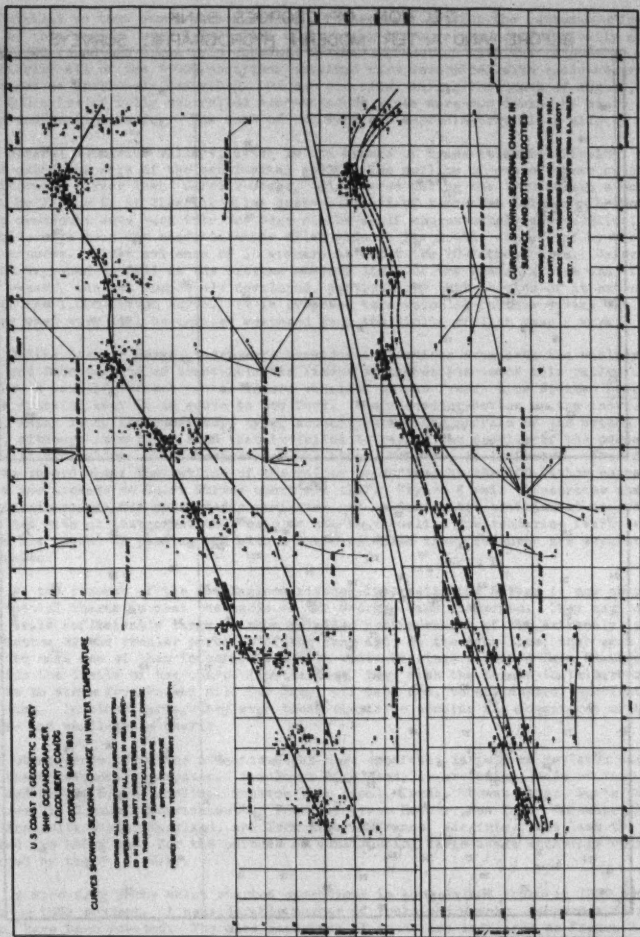
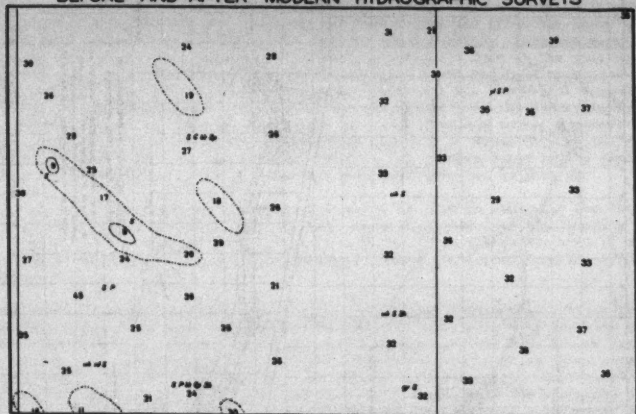


Fig. 3

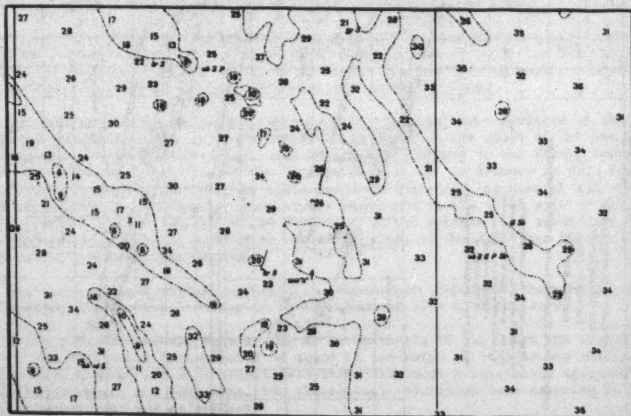
The lower graph of Figure 3 shows the seasonal change in the bottom-velocity of sound throughout the season for the shallower parts of the Bank. It will be seen that, in depths between the surface and 20 fathoms, the velocity of sound increased from 1,480 meters per second at the beginning of the season to 1,510 meters per second during the first half of September, or at the average rate of about one meter per second every four days. This was due entirely to increased temperature, as the salinity remained constant in so far as its effect on velocity was concerned.

The importance of temperature-observations in radio-acoustic work was clearly demonstrated during the season. The average velocity used at the beginning of the

SECTION OF GEORGES BANK BEFORE AND AFTER MODERN HYDROGRAPHIC SURVEYS



1913



1931

Fig. 4

season in carrying distance 70 miles through the main scheme of triangulation was 1,480 meters per second. As a check on this distance, it was redetermined at the end of the season. The discrepancy between the two distances was about 50 meters or one part in 2,600. However, had no account been taken of the change in the temperature of the water, there would have resulted an error of 2,000 meters or one part in 65.

Figure 4 shows a section of chart No. 1107 before and after applying the results of the 1931 season's work. During the course of the season over 8,000 square miles of

area similar to that shown were surveyed. To properly develop the bottom-configuration of this region, over 9,000 miles of sounding-lines were run. Practically all of the 59,000 soundings taken were obtained by the echo-method with the fathometer and practically all of the 7,000 positions obtained were determined with radio-acoustic distances as previously described. On one occasion, during the month of August, more than 500 miles of fully controlled echo-sounding lines were run during 24 hours of heavy and continuous fog. The cost of the work was approximately \$15 a mile.

Several submarine valleys, lying in the tracks of trans-Atlantic shipping, were found along the edge of the continental shelf. The outline of one of these, which is considerably larger than Corsair Gorge, discovered during the 1930 season's work, is shown by Figure 5; it lies 112 miles east-southeast of Nantucket Island. The portion of it presented cuts back into the edge of the shelf approximately eleven miles, is one mile wide near its head and three miles wide at its mouth, as defined by the 200-fathom curve. First evidence of it appears at about the 70-fathom curve. Unfortunately, it happened to fall at the extreme western limit of the season's work and, for that reason, was not completely developed, particularly that portion of it extending out to the 1,000-fathom curve. It is proposed to develop it further during the coming summer when work will be carried westward from the limits of last year's work.

Unlike Corsair Gorge, there were previous indications from both the earlier surveys and from reports of trans-Atlantic liners of the existence of this valley. Figure 6 shows a copy of the echo-meter record obtained on the French Line Steamer DeGrasse while crossing over it en route to New York. The recording-device on the instrument used, which is of the supersonic type, actually draws the profile of the bottom passed over, although it will be seen that it failed to record the profile of the deeper portions of the valley. The steepness of the slope, however, is indicated. The insert on the record shows the outline of the valley as defined by the 100-fathom curve and as it now appears on Coast Survey chart No. 1107. Figure 6 well illustrates the marked advantages the present-day navigator has in fixing his position at sea when provided with an instrument that enables him to visualize the submarine features over which his vessel is passing and with a chart on which these features are accurately portrayed.

At the request of the New England fishing-interests, the Bureau is now compiling two special charts to meet the needs of the Georges Bank fishermen. They desire these on a scale sufficiently large to show detailed configuration of the extremely irregular bottom of the shoaler portions of the Bank and, at the same time, they wish to be able to make use of them in connection with radio bearings received from stations well outside the limits of the chart. Furthermore, they wish the charts to tell them what course to steer from Peaked Hill Bar Buoy, off Cape Cod, to any desired destination on the Bank. In other words, they wish these charts to combine the advantages of both large- and small-scale charts.

Other projects on the Atlantic Coast have consisted largely of revision surveys for chart-correction purposes. Resurveys have been, or are being, made of Port Royal Bar and Sound, South Carolina; Houston Ship Canal, Texas; Chowan River, North Carolina; Pollock Rip Channel, Massachusetts; Port Jefferson Harbor, New York; Wicomico River and Annapolis Roads, Maryland, and York River Entrance, Virginia. The last two mentioned are being made for the purpose of constructing large-scale anchorage charts requested by the U. S. Navy.

A wire-drag party which started operations in Long Island Sound in 1930 continued work on this project. A considerable number of rocks and wrecks, dangerous to navigation, have been located. The more important of these are indicated on Figure 7 by circles, the depth of water over each danger being indicated in feet. In 1930 this party solved the mystery surrounding the loss of a fuel-oil barge which, with its captain and engineer, had disappeared about six months before. After the wire-drag party had located and reported the position of the barge, which had sunk in 53 feet of water, it was salvaged together with 300 pounds of fish found trapped in the hold. In 1931 this party located the auxiliary sloop Sea Fox, lost with nine people aboard on May 22, 1931. This vessel has since been salvaged.

Ten years ago the charts on the Pacific Coast were far from adequate, except those of the principal harbors and their approaches. Since then it has been possible to

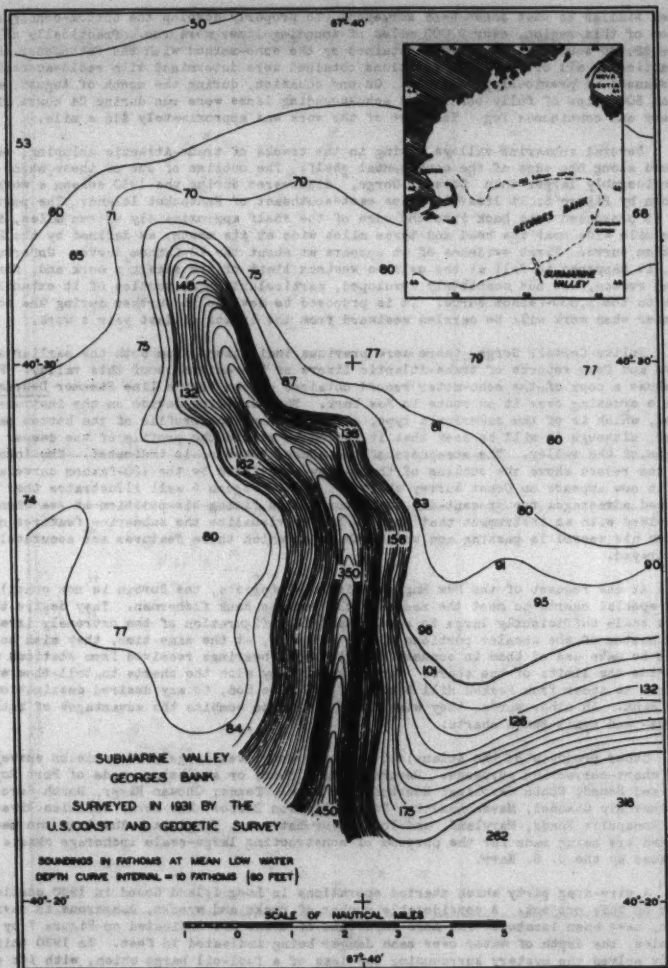


Fig. 5

follow a definite program for improving them. There is shown in Figure 8 a section of chart No. 5802 of the Oregon Coast before and after the application of the type of surveys now being accomplished along the Pacific Coast. These surveys extend offshore at least to the 1,000-fathom curve. During the past year the party on the ship Guide finished work on the Washington Coast so that we now have the data for the construction

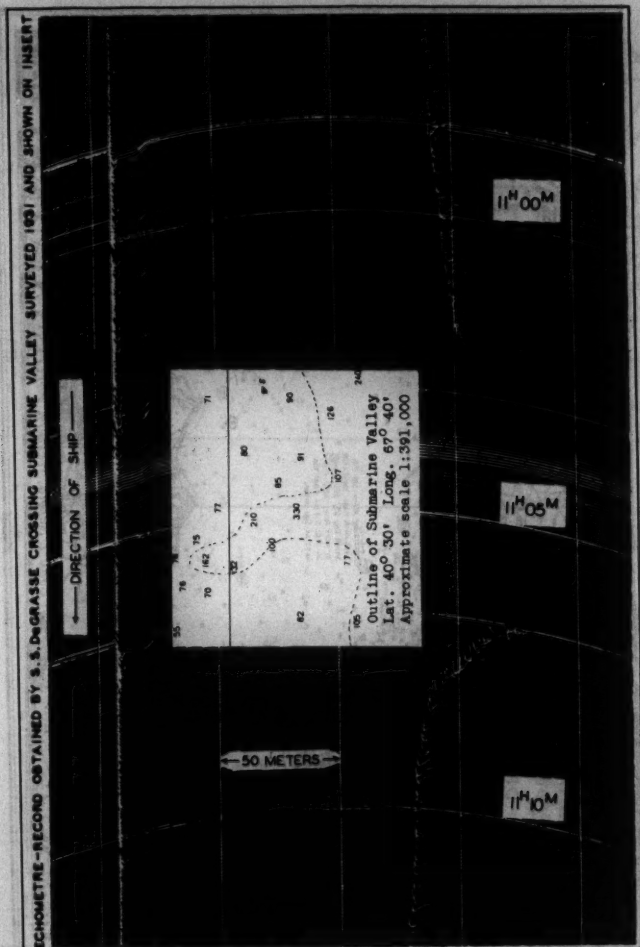


Fig. 6

of modern charts northward from San Francisco to the Canadian border. Carrying out this program has been greatly facilitated, both as regards rate of accomplishment and accuracy of the results, by the employment of echo-sounding and radio-acoustic ranging. The Guide is now continuing this class of work south of San Francisco, although it appears likely at this time that work will have to be discontinued during the next fiscal year.

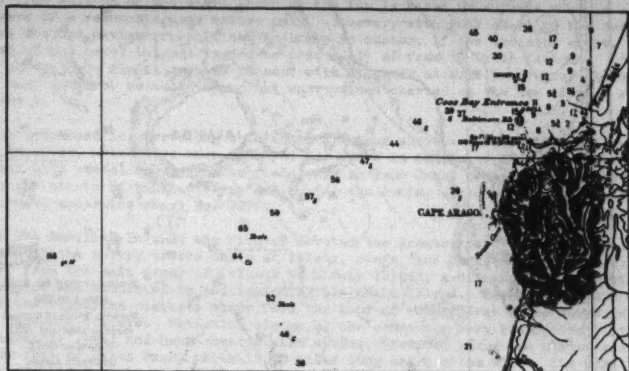


Fig. 7

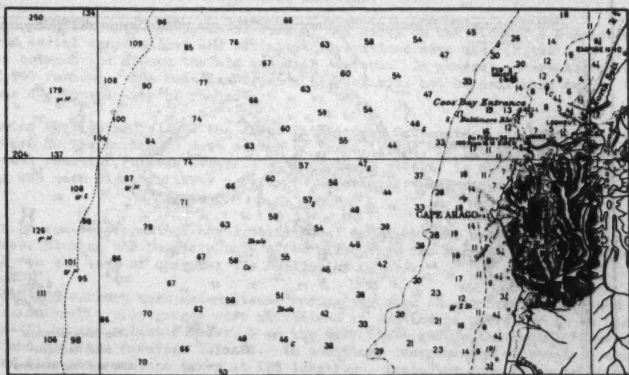
Remarkable progress has been made during the past year by the parties on the ships *Surveyor* and *Discoverer* operating in southwest Alaska. The *Surveyor*, continuing on the extensive project which calls for complete charting of the coast of Kodiak Island, extended work along the southeast coast from Sitkinak Strait eastward to a junction with previously completed surveys in Sitkalidak Strait. This included detailed surveys of Three Saints, Shearwater, and several other bays, some of which, even though offering excellent anchorages, have been practically unknown to exist. The season's

SECTION TYPICAL OF THE OREGON COAST

BEFORE AND AFTER COMPLETION OF MODERN HYDROGRAPHIC SURVEYS



1918



1931

Fig. 8

accomplishment furnishes data for charting the greater portion of the areas embraced by new charts Nos. 8536 and 8537.

The *Discoverer*, continuing on the project along the south side of Kenai Peninsula, extended surveys westward to a junction with previously completed work in the vicinity of Chugach Islands and across the Strait to Shuyak Island. The season's work furnished the field data for the construction of proposed chart No. 8532.

Together the parties on the *Surveyor* and *Discoverer* ran more than 16,000 miles of sounding-lines and in connection with their hydrographic work made many serial

CONTRAST BETWEEN ADEQUATE AND INADEQUATE SURVEYS

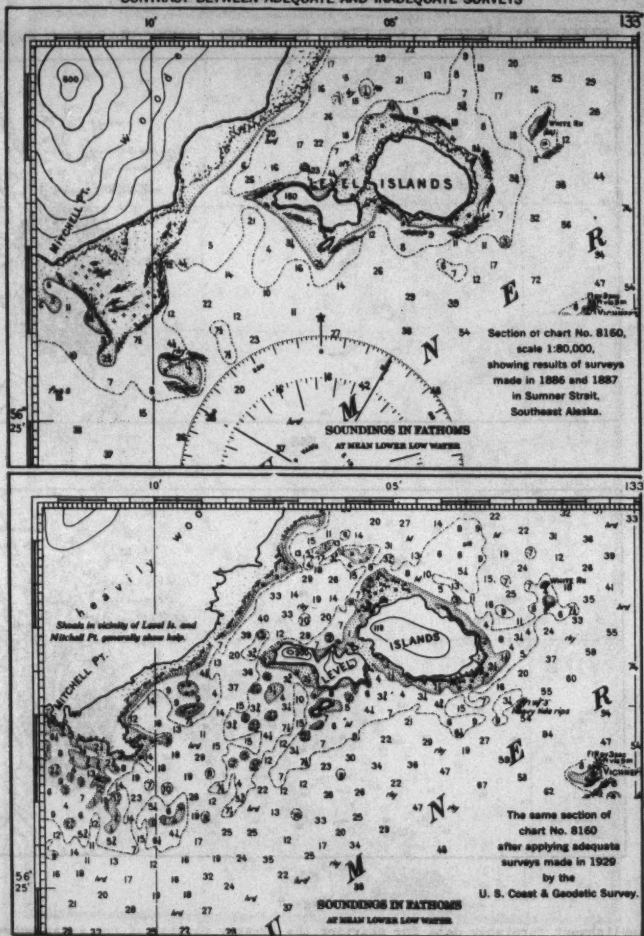


Fig. 9

temperature- and salinity-observations well distributed throughout the season in various sections of their field of work.

The principal steamer-tracks in southeast Alaska have been surveyed and many of them have been dragged. There still remains, however, much work to be done before it can be said that southeast Alaska is adequately charted. Many localities only slightly removed from main steamer-tracks, where larger vessels might have occasion to seek

anchorage or where smaller vessels might endeavor to shorten their routes, are inadequately surveyed. Figure 9 shows a section of chart No. 8160 embracing the region in the vicinity of the Level Islands, just off the main steamer-track to Wrangell and Juneau. The edition of the chart shown at the top is based on surveys made in 1886-87 which were of a reconnaissance nature only. However, with this chart in his possession the average navigator would not hesitate to anchor, if the occasion arose, southward of the Level Islands in depths presumably of from 10 to 15 fathoms. If he did so he would be almost certain to meet with disaster as will be seen by glancing at the many dangers, revealed by modern surveys and charted on the new edition shown in Figure 9.

The data used in correcting this chart are from surveys made in 1929 by the party on the *Explorer*, which have been employed for years in southeast Alaska. During the past year this vessel completed the field work in Behm Canal necessary to construct new large-scale charts of that waterway and during the coming season will make the surveys necessary to modernize chart No. 8076.

In the Hawaiian Islands the *Pioneer* devoted the greater part of the year to the extension of the survey of the chain of islets, reefs, and banks which extend northward from the main group of islands to Midway Island, a distance of 1,100 miles. This project was completed to and including Lisianski Island. Detailed surveys were made of the submarine plateaus which form the tops of what appear to be submerged or eroded volcanic craters. While the slopes of the cones are very steep, the plateaus are remarkably level and have considerable extent. Notable among the plateaus developed was that of Raita Bank, which is 20 miles long and 8 miles wide. The peculiar feature of this Bank is that while depths over the greater part of it are very regular, and range from 19 to 21 fathoms, it does have on the extreme southeast edge a very definite ridge, one mile in width and 12 miles long, on which there are depths as shallow as 10 fathoms, the bottom being coral and sand.

In connection with hydrographic work of the party on the *Pioneer* a considerable number of serial temperature- and salinity-observations were made in the deep areas that lie between and around the old volcanic craters. In general, these depths are about 2,500 fathoms. The Hawaiian Islands project will not be continued during the next year due to scarcity of funds.

In the Philippine Islands the ships *Pathfinder*, *Fathometer*, and *Marinduque* continued work on the north and east coasts of Luzon Island, in the Sulu Archipelago and on the west coast of Palawan Island. Each of these vessels is equipped for echosounding and each has a definite program for obtaining water-temperature and salinity data.

The recent settlement of the International Boundary Line between the Philippines and Borneo, placing the boundary only a few miles from the Borneo Coast, has added appreciably to the task of charting the Philippine waters.

Tidal and current work accomplished during the year can be briefly outlined as follows: Automatic tide-gauges were maintained in continuous operation at 48 tide-stations--21 on the Atlantic Coast, 3 on the Gulf Coast, 19 on the Pacific Coast, 3 in Alaska, and 2 in the Hawaiian Islands. In addition, records were received of shorter series of tide-observations taken at 125 locations, including some taken by other organizations and private agencies. These series of tide-observations furnish data for the tidal control of hydrographic surveys and the precise determination of the tidal datum-planes. The shorter series are for the most part taken in connection with hydrographic surveys, the values obtained from them being corrected by comparison with the continuously operated stations.

The field work of a comprehensive tide- and current-survey of Buzzards Bay and vicinity, Massachusetts, was executed during the past season. Tide-observations were secured at 23 locations and a total of 160 days of current-observations were taken at 95 current-stations. The detailed results of these observations are now being prepared for publication.

During the year series of continuous hourly current-observations of approximately 18 months each were completed at two lightship-stations located at the western en-

trance of Vineyard Sound and Buzzards Bay, Massachusetts. A similar series covering one year was completed off the entrance to Narragansett Bay, Rhode Island. These observations were made possible through the cooperation of the Lighthouse Service.

During the past season's work on Georges Bank off the Massachusetts coast, current-observations were secured at each of the control-buoys occupied by hydrophone station-ships. These observations are now being reduced and analyzed. A rotary tidal current of considerable velocity prevails in this area.

In addition to the current-records from Buzzards Bay, Georges Bank, and the lightships just mentioned, records of current-observations at about 200 other locations, including many taken by other organizations, were received in the Office.

The work of preparing for publication the descriptions and elevations of tidal bench-marks along the coasts of Maine and Washington has progressed during the year. Five states on the Atlantic Coast and two states on the Pacific Coast are now covered by such publications which make readily available the datum-planes derived from tide-observations.

The tide-tables as now published annually give daily predictions of all the high- and low-waters for the year at 94 principal ports of the world and a table of differences and constants by means of which similar information may be readily obtained for about 4,000 other locations. The current-tables give predictions for thirteen principal stations on the Atlantic Coast and eleven on the Pacific Coast. They also give data which will permit predictions to be made at 1,200 other places by reference to the principal current-stations. Pocket-size tables, including predictions for both tides and currents, are now issued annually for four important waterways, namely, Massachusetts Bay, New York Harbor, San Francisco Bay, and Puget Sound. Tidal current-charts are now being issued for Boston Harbor, New York Harbor, and San Francisco Bay.

U. S. Coast and Geodetic Survey,
Washington, D. C.

ON THE PENETRATION OF DAYLIGHT INTO THE SEA

E. O. Hulburt

(Abstract)

During descents into the sea to depths of over 1,400 feet Beebe observed that the color of the water during the midday hours of a sunny day was a pure blue and measured the candle-power of the illumination at various depths down to 800 feet (Beebe, Bull. New York Zoological Society, v. 33, 201, 1930). At 800 feet the spectrum was a narrow band centering about wave-length 520 μ . The absorption of light in the visible and ultraviolet portions of the spectrum by samples of pure sea-water taken from the Gulf Stream, the Atlantic and Pacific oceans, and the Caribbean Sea far from land have been measured in the Laboratory (Hulburt, J. Opt. Soc. Amer., v. 13, 555, 1926, and v. 17, 15, 1928). Using the Laboratory absorption-coefficients and the Raman-Einstein-Smoluchowski theory of the scattering of light in liquids, it is found that the spectrum of the daylight at 800 feet in the sea has a maximum brightness at about 500 μ . This agrees with Beebe's result probably within the error of the observations.

The calculated candle-powers of the undersea daylight illumination were greater than the observed values. The assumption that the absorption in the sea below 200 feet was the same as the Laboratory measured absorption and in the surface-layers down to 200 feet was about five times the Laboratory value led to good agreement between the observed and calculated candle-powers at all depths. The surface-layer absorption would be accounted for if 25 millionths of the volume of the water was occupied by opaque material. This would amount to the absorption produced by one small fish per cubic meter of size 6 by 2 by 2 cm, or by opaque notes in the water, of animal, vegetable, or mineral origin, of area about 0.1 square millimeter and one note per cubic centimeter. If the notes were smaller the number of them would be proportionately larger. [The complete paper will appear in J. Opt. Soc. Amer.]

U.S. Naval Research Laboratory, Bellevue, Anacostia, D. C.

PHOTOELECTRIC MEASUREMENTS (MADE DURING THE SUMMER OF 1930) OF THE PENETRATION OF LIGHT (WAVE-LENGTH 2,900 TO 4,800 ÅNGSTRÖM UNITS) IN SEA-WATER, AND THE RESULTS OF LABORATORY PHOTOELECTRIC MEASUREMENTS (MADE DURING THE SUMMER OF 1931) OF THE ABSORPTION-COEFFICIENT OF SEA-WATER

Burt Richardson

(Abstract of research in cooperation with Southern California Telephone Company)

Shelford and Gail on Puget Sound, Washington, and Poole and Atkins in the English Channel off Plymouth, England, determined quantitatively the penetration of light for various depths in sea-water by the photoelectric cell method using electrical circuits with high sensitivity. Attempts to apply their data to another area, such as the Pacific Ocean near San Diego, California, could not be done, nor would the application of their figures to such an entirely different body of water be justified. Therefore, during the summer of 1930, an area seven miles off the coast of La Jolla (city of San Diego), California, was studied by submerging a Burt photoelectric sodium-vacuum cell to various depth-levels in the ocean.

Results indicate that about 21 per cent of the light (wave-length 2,900 to 4,800 Ångström units to which the photoelectric cell is sensitive) is absorbed by the first one-half centimeter of water, that about 50 per cent is absorbed by the first meter, 88 per cent by the first 10 meters, and over 98 per cent is absorbed by 50 meters of sea-water.

During the summer of 1931 sea-water samples were brought to the Laboratory and the absorption-coefficient of sea-water was determined by using four photoelectric cells (Burt sodium-vacuum, Raytheon photocell-potassium, Bell Laboratory caesium-argon, and Weston photronic cell) which were sensitive to a definite band of wave-lengths. Theoretical depths of penetration of these bands of light were then computed by means of the absorption-coefficients.

Mean values of the absorption-coefficient of sea-water determined by 36 sample-readings and computed depth to reduce incident light to 1/2, 1/4, 1/10, and 1/100 of the surface-value

Wave-length of maximum effect on photoelectric cell in Ångström units	Absorption-coefficient, α	Depth in meters			
		1/2	1/4	1/10	1/100
4,000	0.0017	4.1	8.2	15.5	27.00
4,700	0.0007	9.9	19.8	38.0	66.0
4,800	0.0006	11.5	23.0	38.5	77.0
5,000	0.30	0.023	0.046	0.077	0.154
(5,700)	(0.0004 fresh water only)				

In the Laboratory experiments the absorption-coefficients are higher than those for pure water.

A difference in the value of the absorption-coefficient for a single wave-length was observed in observations at sea while in the Laboratory no such difference could be observed. Light near the center of the visible spectrum penetrates to greater depths in sea-water than the blue or red wave-lengths. This is similar to pure-water penetration.

Scripps Institution of Oceanography,
La Jolla, California

LANDSLIDE-MODIFICATIONS OF SUBMARINE VALLEYS

Francis P. Shepard

Introduction--The continental shelves are accordant in level to such a degree that they must have been remarkably free from earth-movements both during and since their formation. Yet these same stable shelves are traversed in many places by deep elongate depressions many of which are so similar to river valleys that they have been attributed to the submergence of the continental borders. Since most of the valleys have bases thousands of feet below sea-level how could the sinking have occurred without throwing the shelves out of adjustment? A deep submergence at present would not only deform the shelf but would also cause deep indentations into the lands along the sides of the submerged valleys, but the coasts inside most of the submarine valleys are essentially straight. Obviously if these valleys were cut by rivers and then submerged this must have happened prior to the formation of the continental shelves and enough time must have elapsed to eliminate the estuaries which the submergence produced. Here again we meet obstacles. If the valleys have been submerged for a long time, why have they not been filled by sedimentation attendant upon the formation of the continental shelves? Also the valleys show various signs of recency such as their steep sides and their situation directly off rivers which are actively depositing sediment.

Does all of this contradictory evidence make it necessary to abandon the attractive idea that these features were once river valleys and to turn to such remote possibilities as that submarine currents are sufficiently powerful to excavate canyons out of rock to depths of many thousands of feet or that the same results are the product of submarine solution? If not how could valleys have been submerged for a long time and still have the appearance of recent origin? The following sequence of events appears to satisfy these conditions: First, the erosion of valleys on elevated continental margins; second, submergence of the margins to considerable depths below sea-level; third, the cutting of continental shelves with deposition in the submarine valleys; and fourth, reopening of the submarine valleys by landslides caused largely by earthquakes accompanying faulting-action along the continental slopes.

There are various reasons to believe that landsliding is the principal factor in producing the present character of the valleys. The steep continental slopes beyond the shelves, the abundance of fine saturated sediment in the valleys, and the association of valleys with seismic areas make their situation ideal for sliding. The depressions and hummocks characterizing the topography of the valley-floors also suggest landsliding.

Recent submarine landlides--Corsair Gorge--Without going into the evidence for earlier landlides any further, I should like to present some evidence of recent landsliding. Shortly after the Grand Banks earthquake, a ship reported that the outer edge of the continental shelf east of Nantucket Lightship had foundered. The report was not generally credited till the United States Coast and Geodetic Survey examined the area and found a typical submarine valley (Fig. 1). Since this valley is along one of the main routes to Europe and in about the position where in-bound steamers take soundings to see whether they are on the shelf, it seems strange it had not been reported previously. Captain Johnson of the *Columbus* evidently crossed the area many times with his echo-sounding apparatus running prior to the earthquake but never observed the valley. It seems likely, therefore, that the valley either came into existence or was greatly extended at the time of the earthquake. The changes necessary to produce such a feature are much greater than any earth-movements ever reported as accompanying earthquakes. On the other hand, such changes have occurred during land-slides. The hummocky topography associated with the valley makes it very evident that the feature has been subject to such action.

Esmeraldas, Ecuador--Since obtaining this evidence from the east coast of the United States, I have found that there is substantial evidence of deepening of submarine valleys in two other places. The first case reported was off the west coast of South America (Fig. 2), where a deep submarine valley extends beyond the Esmeraldas River of Ecuador. Milne (John Milne, Sub-oceanic changes, *Geog. J.*, v. 10, 263, 1897) reported that cables in the bottom of this valley had been broken in a number of places, and when the area was resurveyed soundings revealed that there were changes

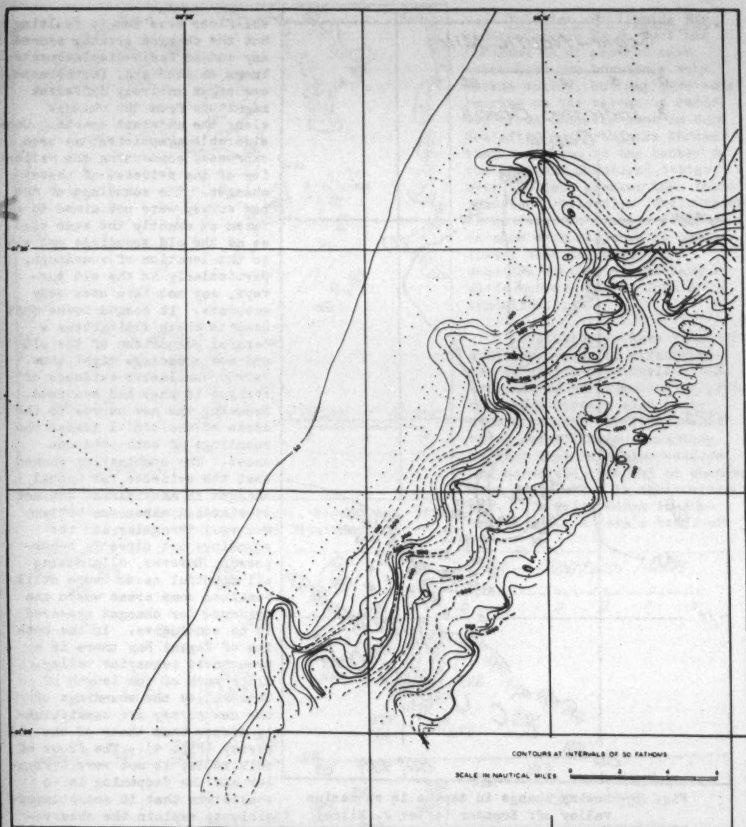


Fig. 1--Corsair Gorge, a submarine valley discovered recently in the outer edge of Georges Bank (contours subject to corrections)

from depths of 15 to 20 fathoms to upwards of 200 fathoms. These changes seem quite authentic since the soundings were taken near the shore using cross-bearings. Furthermore, the Commercial Cable Company reports that they have an especially large amount of trouble with cable-breaks caused by slides where the cables cross submarine valleys off the west coast of South America (personal communication).

Sagami Bay, Japan--When the Japanese made a resurvey of Sagami and Suruga bays after the great earthquake of 1923 they found that there was evidence of extensive changes in the ocean-floor. They constructed a map showing lines of equal changes (Fig. 3). At first sight it might appear that in this case the changes of the bottom could not be attributed to landslides since these are indications of both elevation and depression. There has been a common assumption that these modifications of the

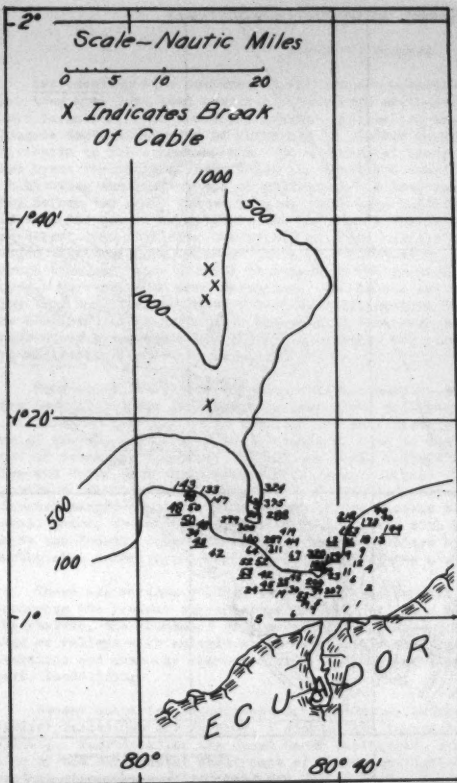


Fig. 2--Showing change in depths in submarine valley off Ecuador (after J. Milne)

locations. In two other localities there is probable evidence of deepening; one is in the submarine valley at the entrance of Tokyo Bay and the other in the submarine valley of Suruga Bay. The latter is particularly significant since it is far enough from the centre of the earthquake so that it could not be attributed to faulting. The evidence of rise in the bottom of the Bay is for the most part very uncertain. Probably one area has had a decrease in depth, but this area contains deep water and is situated at the foot of a steep slope.

Under this revised view of the situation there seems to be little reason to doubt that the changes were of a landslide nature. The material which had accumulated in the deep valleys was naturally of a fine texture and accordingly very subject to sliding. The powerful earthquake would have been just the type of cause likely to start such slides. The rise in the bottom at the base of a slope could be explained by dislodgment of material from above and accumulation below. The magnitude of the changes is not inconsistent with landslides and the probable change in Suruga Bay is certainly favorable to an explanation of this sort.

sea-floor were due to faulting but the changes greatly exceed any sudden fault-displacements known on land and, furthermore, are of an entirely different magnitude from the changes along the adjacent coasts. Considerable skepticism has been expressed concerning the validity of the evidence of these changes. The soundings of the new survey were not aimed to be taken at exactly the same places as the old soundings and also the location of soundings, particularly in the old surveys, may not have been very accurate. It seemed to me that despite these limitations a careful comparison of the old and new soundings might show fairly conclusive evidence of changes if they had occurred. Reducing the new survey to the scale of the old, I traced the soundings of both onto one sheet. The combination showed that the evidence for actual changes in many places was not substantial since the bottom was very irregular and the soundings not directly superposed. However, eliminating all doubtful cases there still remained some areas where the evidence for changes appeared to be conclusive. In the bottom of Sagami Bay there is a pronounced submarine valley. Along much of the length of this valley the soundings of the new survey are consistently deeper than those of the old survey (Fig. 4). The floor of this valley is not very irregular and the deepening is so consistent that it seems impossible to explain the observations on the ground of faulty

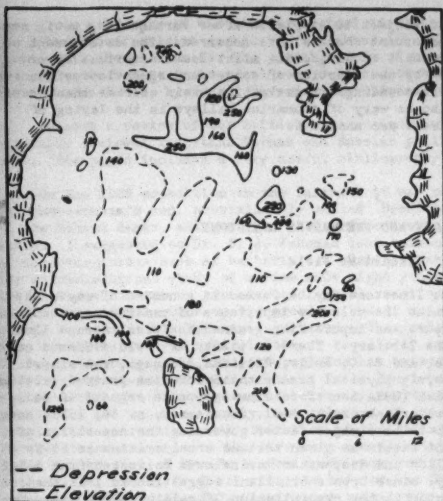


Fig. 3--Equal depth-change lines, Sagami Bay, after Japanese Hydrographic Department

Sulu Sea, Philippine Islands--Captain N. H. Heck has informed me of another case which does not involve a submarine valley, but may have some bearing on the cases. A resurvey of an elongate bank in Sulu Sea after an earthquake showed that a section in the center of the bank had developed depths over 100 feet greater than those reported previously. While there is no very substantial evidence to show what happened it seems likely that the earthquake caused a section of the bank to glide outward in the form of a landslide.

Conclusions--These items of evidence appear to strengthen the landslide hypothesis as an explanation of submarine valleys, but there appears also to be some practical significance to these observations since they suggest that submarine valleys are especially subject to changes from earthquakes in their vicinity. Since soundings in submarine valleys form a basis of

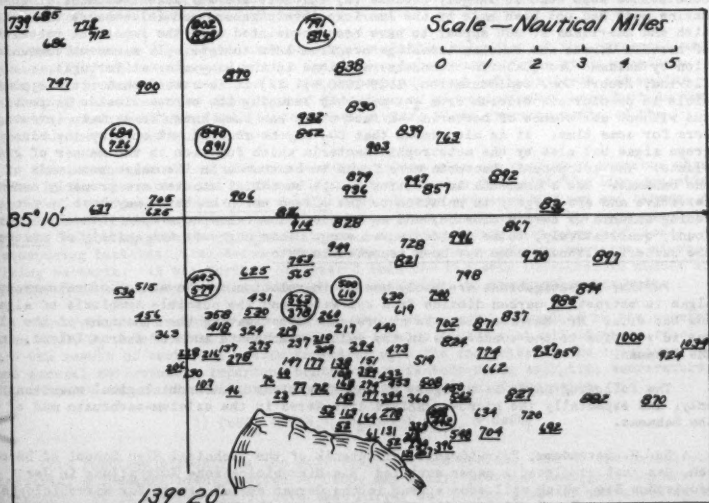


Fig. 4--Comparison of old and new (underlined) soundings in portion of Sagami Bay along the axis of a submarine valley

navigation, perhaps they should be subject to suspicion after earthquakes, until new surveys have determined whether important changes have occurred. The development of a new submarine valley close to the coast of California might lead to serious errors. This danger is perhaps accentuated by the adoption of echo-sounding devices since vessels so equipped will be using more soundings in navigating their courses than previously. Cable companies should also be wary of submarine valleys in the laying of their submarine cables if these areas are unstable.

University of Illinois,
Urbana, Illinois

MICROBIOLOGY AND THE MARINE LIMESTONE

Richard M. Field

There is no question but that limestone may be formed in a number of ways, nor are we yet in a position to determine the relative importance of numerous agents in the formation of the bulk of our pure and impure fine-grained, unfossiliferous limestones from the Pre-Cambrian to the Tertiary. There is plenty of field evidence as to the clastic origin of limestones, and R. C. Wells, Williams, Johnson, and others have shown the possibility of a purely physical precipitation of fine-grained calcium carbonate. Recently Parker D. Trask (Relation of calcium-carbonate content of sediments to salinity of the surface-water, abstract, Geol. Soc. Amer., p. 34, 1931) has stated that he has found salinity to be a major factor governing the deposition of calcium carbonate. This statement should be given serious consideration as it is founded upon 3,000 samples of shallow and deep-water marine muds collected from all parts of the world. Unfortunately, since Drew's brilliant suggestion in 1911 that bacteria might be an important factor in the precipitation of calcium carbonate, numerous investigations along this line, especially by Americans, have led to the growing belief that bacteria are a negligible factor. It would appear that these conclusions were reached largely because (a) suitable and sufficient studies of the marine muds had not been made by the American investigators and (b) because the British and Americans do not appear to have been acquainted with the important researches of certain German and Russian investigators from 1899 to date. In a recent communication by Haldane Gee (Calcium-carbonate relations in the sea-water at Tortugas, Florida, Report Com. Sedimentation, 1929-1930, p. 12) it is stated that "it was possible to precipitate calcium from sea-water by reducing its carbon-dioxide content, and without assistance of bacteria -- a fact which has been known to certain investigators for some time. It is also known that CO_2 may be removed not only by the blue-green algae but also by the autotrophic bacteria which function in the manner of green plants. The autotrophic bacteria were found to be common in the calcareous muds of the Bahamas. Gee's comments in relation to his bacterial studies are properly conservative and are largely in relation to the effect which bacteria may have in producing ammonia or carbon dioxide, and he states, "The calcareous muds themselves were found, qualitatively, to be decidedly reducing. This suggests the acidity of anaerobic bacteria although none has been reported to date."

Further investigations are badly needed in relation to the action of calcareous algae in extracting carbon dioxide from sea-water and the possible symbiosis of algae and bacteria. Mr. Maurice Black is at present investigating the functions of the algae in relation to the conditions in the calcium-carbonate muds of Andros Island, in the Bahamas.

The following paper is a digest of investigations on microbiological reactions only, and especially the micro-organisms discovered in the calcium-carbonate mud of the Bahamas.

Dr. W. Bavendamm, Privatdozent der Botanik of the Technical High School of Dresden, has just completed a paper entitled "Die Mikrobiologische Kalkfällung in der Tropischen See" which will soon appear in the German serial *Archiv für Mikrobiologie* as Contribution No. 7, International Expedition to the Bahamas.

Dr. Bavendamm's paper not only brings up-to-date the microbiological investigations of the expeditions which Princeton has been sponsoring in the West Indies, but

also gives a history of the microbiological investigations in their relation to the precipitation of calcium carbonate from about 1889 to 1931. (An earlier paper connected with the problem is The possible role of micro-organisms in the precipitation of calcium carbonate in tropical seas, International Expedition to the Bahamas, Contribution No. 6, by Werner Bavendamm, published in Science, May 29, 1931.)

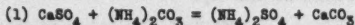
Besides a review of the British and American investigations, the author has carefully reviewed important German and Russian publications which have appeared since 1918. The paper includes a very useful bibliography of 143 titles.

On the 1928 expedition to the Bahamas, it was noticed that the fine-grained calcium-carbonate mud, provisionally called *Dreiwite*, which covers such a wide area on the Bahama Banks, changed from the surface downward from white through grey to black. I suggested to Dr. S. A. Waksman that this change might be due to the action of micro-organisms such as bacteria. I also suggested that it was quite possible that the microbiological study of marine muds might yield far more important results than the previous studies on the microbiological reactions in sea-water. Dr. Waksman very kindly consented to take up the problem, and it was arranged that Dr. Bavendamm should do the work under Dr. Waksman's guidance. The geological significance of Dr. Bavendamm's work is not yet entirely clear, especially as Mr. Maurice Black, Fellow Trinity College, Cambridge, has not yet completed his researches on the sedimentation and stratigraphy of Andros Island; but it is at least possible that the information which the microbiologists have given us bears an important relation to the major sedimentary problem in the Bahamas, namely, the relation of the stability of the islands to the origin, transportation, and alteration of the sediments which mantle their surfaces. Further information as to the structure and stability of the islands has been produced by the work of Dr. F. A. Vening Meiness, of the Geodetic Commission of the Netherlands, and H. H. Hess, with the help of the United States Naval vessels, the submarine S-48 and the S.S. *Chewink*. A relatively close net of 54 gravity-stations has been made in the West Indies and a traverse of over 4,000 miles of supersonic soundings. Twelve gravity-stations have also been established on the islands by the United States Coast and Geodetic Survey. It is later planned to check the gravity by means of detonation and seismograph.

Dr. Bavendamm's paper on microbiology is chiefly valuable, at the present time, because (1) it gives the geologist a fairly complete review of the study of microbiological processes in relation to the precipitation of CaCO_3 in fresh and marine waters, (2) discusses the technique of this type of microbiological work both in the laboratory and the field, and (3) describes a micro-flora characteristic of the tropical, marine, calcareous facies.

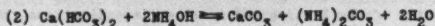
The author assures us that the bacteria in the muds are much more numerous than those in the sea-water, and confirms Lipman's conclusion that strictly lime-secreting bacteria, *Pseudomonas* (*Bacterium calcis*) such as were proposed by Drew and others, do not exist. A rich variety of bacteria, however, was discovered in the muds, including the following groups: Sulphur-bacteria; agar-liquefying bacteria; cellulose-decomposing bacteria; urea-decomposing bacteria; sulphate-reducing bacteria; nitrogen-fixing bacteria. It was further discovered that the bacteria increased in number and species from the normal marine, through the estuarine, to the fresh-water muds.

The following reactions are given as those which may be involved in the precipitation of CaCO_3 under natural conditions. It is also stated that all of these reactions are the result of bacterial action dependent upon the character of the solutions, muds, and general environment; important contributory factors being salinity, temperature, CO_2 -content, amount of sunlight, and depth, and agitation of the water.

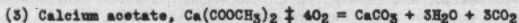


This reaction probably is the most important one because, due to the ammonifying bacteria, a constant precipitation of CaCO_3 may occur, provided CaSO_4 and CO_2 are abundant. It is interesting to note that Murray and Irvine spoke of the above as an animal reaction. The main supply of ammonia appears to be due to the action of the proteus subtilis and the fluorescent group of bacteria which cause the decomposition of the proteins and thus lead to the formation of ammonia. The fermentation caused

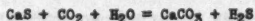
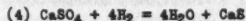
by the urea-decomposing bacteria is also of probable importance in this connection. A further but less plentiful supply of ammonia is the result of nitrate reduction; that is, the reduction of nitrates to nitrites and ammonia. The so-called lime-bacteria of Drew and others are chiefly the nitrate-reducing ones. All of the forms mentioned above were found to be abundant in the calcareous muds.



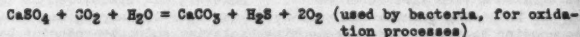
When water is saturated with calcium bicarbonate and ammonia is formed by the action of bacteria, CaCO_3 is precipitated by the above reaction (2). In a recent letter R. L. Ginter made the following suggestion: The calcium from the land is carried in solution as bicarbonate to the sea, which for the purpose of simplicity may be divided into two zones: The upper oxygen-zone, penetrated by light, the habitat of a prolific chlorophyll-bearing life; and the lower, or bottom deoxygenated zone, the habitat of a prolific denitrifying bacteria. The precipitation of calcium carbonate would result in the upper zone because of the utilization of CO_2 from solution by the chlorophyll-bearing life (algae and autotrophic bacteria). The equilibrium (reversible reaction $\text{Ca}(\text{HCO}_3)_2 \rightleftharpoons \text{CO}_2 + \text{H}_2\text{O} + \text{CaCO}_3$) would be disturbed due to the increase of the pH, that is, a pH at some point above 7.0 would bring about the precipitation of CaCO_3 from a definite amount of the bicarbonate of calcium. The precipitation of calcium carbonate in the bottom-zone would result mainly from the action of anaerobic, denitrifying bacteria (putrefaction-bacteria). Here, also the calcium-bicarbonate equation would be disturbed because of the pH increase (OH-ion increase) and calcium carbonate would be precipitated, according to reversible reaction (2).



The above reaction may take place where denitrifying bacteria, as well as other forms, act in a solution which is rich in organic calcium salts. The presence of appreciable amounts of organic calcium salts in the tropical seas has been questioned. Berkley has suggested that acids may arise through the decay of seaweed which, reacting with CaCO_3 , would produce organic calcium-salts. A number of acid-producing bacteria have been found in the Bahama calcareous muds such as the butyric-acid bacteria, cellulose-decomposing bacteria, thermophilic bacteria, agar-liquefying bacteria, etc. It should also be noted, however, that the latter have been shown to produce CO_2 . Organic lime-salts also occur in the calcareous algae and cocco-lithophores. Drew's view is thus valid as regards the assumption that CaCO_3 may be produced by the decomposition of calcium salts of organic acids.



OR



According to both Murray and Irvine and Hadson reaction (4) is performed by the sulphate-reducing bacteria. According to Issatschenko the bacterium *Microspira aestuarii* produced H_2S and appreciable amounts of calcium carbonate per gram of moist mud. The sulphate-reducing bacteria were found to be particularly abundant in the Bahama calcareous muds under distinctly anaerobic conditions. Further, these bacteria were found to flourish in both the salt-water, brackish, and fresh-water muds. It is suggested that the presence of appreciable amounts of CaCO_3 in estuarine muds and shaly facies might be formed in this way.

Conclusions--The close association of many types of bacteria in the calcium-carbonate mud of the Bahamas may be responsible for at least part of the CaHCO_3 which is usually found to be present in solution as bicarbonate. Other bacteria, already mentioned, tend, at times, to remove the CO_2 , and cause the precipitation of CaCO_3 . The problem, therefore, includes not only the direct precipitation of CaCO_3 but also the production of calcium bicarbonate. What is of importance in the preceding is the suggestion that all of the above reactions may be directly or indirectly the result of bacterial action. It has not yet, however, been proved that these reactions do take

place, or if they do, that they are particularly effective in the production of CaCO_3 . It is interesting to note, however, that all the elements are present to produce the reactions, especially in the fresh and brackish waters of the area.

I believe that the conclusion is therefore justified that, while there are no purely lime-secreting bacteria, certain bacteria are important factors in the precipitation of calcium carbonate; and that they become of increasing importance off a calcareous coast line as we proceed from marine toward brackish and fresh-waters.

The geological significance of the microbiological investigations in the Bahamas appears, for the present, to be as follows:

(1) Microbiological reactions which might produce CaCO_3 do not appear to flourish in shallow, normal marine-waters where there is an abundance of sunlight and relatively constant agitation of the bottom-muds. As these appear to be the conditions under which the bulk of the fine-grained, pure unfossiliferous limestones were deposited from the Pre-Cambrian to at least the Mesozoic it is suggested that microbiological reactions could not have precipitated important quantities of CaCO_3 from the ancient seas unless they were, at least, quite different solutions from that represented by present-day, normal seas.

(2) CaCO_3 may be precipitated in deep lagoons or enclosed arms of the sea, largely by microbiological processes. It is obvious, however, that this method of precipitation will not explain the bulk of the marine fine-grained nonfossiliferous limestones throughout geologic time.

(3) CaCO_3 might be deposited by microbiological means, under estuarine conditions, the preponderance of the calcium salts varying inversely with the amount of argillaceous muds and elastic sediments.

(4) The bulk of the calcareous mud which underlies the sea-water of the Bahama Bank, however, has been shown to have been derived from the calcareous mud from Andros Island.

(5) The calcareous mud of Andros Island is probably of either brackish- or fresh-water origin.

(6) Microbiological investigations in the West Indies region to date intimate that when a calcareous reef or shelly beds or elastic calcareous material such as coarse or fine sand are raised above sea-level the optimum physical, chemical, and biochemical conditions obtain for the solution and redeposition of fine-grained, relatively pure calcareous mud. Thus considerable quantities of pure fine-grained carbonate muds may be made available for transportation and deposition in the sea.

(7) Since these calcareous muds are relatively insoluble in normal sea-water and are also quite resistant to lithification except under conditions of deep burial, it is suggested that the sediments which form the bulk of the unfossiliferous limestones throughout geological time have had a long and varied inheritance, and have accumulated from time to time in geosynclines and basins in much the same manner as other muds, regardless of their mode of origin.

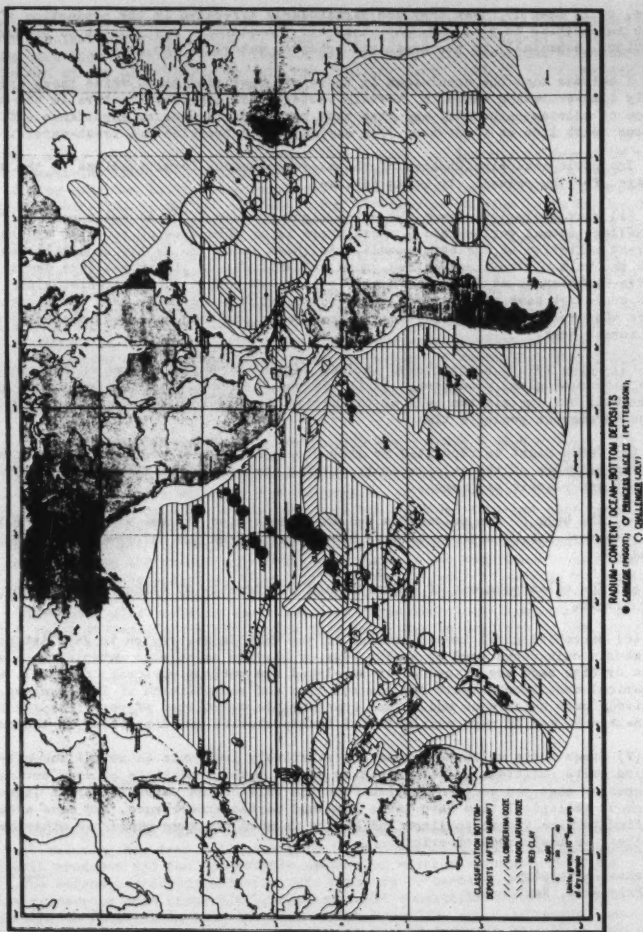
Princeton University,
Princeton, New Jersey

RADIUM-CONTENT OF OCEAN-BOTTOM SEDIMENTS

C. S. Piggot

Many determinations of the radium-content of various rocks from many localities on the continental surfaces of the Earth have been made, but very few such measurements have been made on the materials comprising the ocean-bottom sediments.

The reason is obvious, but when the vast area of these sediments is considered, and especially their high radium-content, it is most desirable that more such measure-



ments should be made. Joly (J. Joly, Phil. Mag., v. 16, 190, 1906) has reported twelve such determinations on samples taken by the Challenger and Albatross; and Hans Pettersson (Teneur en radium des dépôts de mer profonde; Fascicule LXXXI of Resultats de Campagnes Scientifiques par Albert I^{er} Prince Souverain de Monaco 1930) 28 determinations on samples, some of which were from the Challenger collection, and the others from the collection of the Prince of Monaco, having been taken by his yacht the Princess Alice II.

Two of Pettersson's analyses were of the same Challenger sample as used by Joly, and in each case Pettersson's figure is lower than Joly's.

This accords with Joly's own opinion that his early figures were too high, and he has subsequently, in some cases, revised them downward.

To these meager data we are able to add 28 other determinations made on samples by the Carnegie on her last cruise. (The samples were made available for study through the kindness of J. A. Fleming, Acting Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington.) Of the many bottom-samples taken by the Carnegie only those which were of sufficient bulk to permit other studies as well were used for radium-determinations since these tests, of necessity, destroy the material used.

The data of Joly and Pettersson are repeated in Tables 1 and 2, while those of the Carnegie samples, which with one exception (station 6) were taken in the Pacific Ocean, are given in Table 3 below.

Table 1--Radium in ocean-bottom sediments (Joly)

Latitude	Longitude	Depth	Type of sediment	Radium
				$g \times 10^{-12}$ per g
" "	" "	meters		
38 34 N	72 10 W	2268	Blue mud	3.1
51 37 N	12 10 W	1040	Globigerina ooze	6.6
38 06 S	88 02 W	3538	Globigerina ooze	7.4
21 13 S	14 02 W	3640	Globigerina ooze	6.7
48 17 N	39 49 W	4560	Globigerina ooze	7.0
22 11 S	133 21 W	3735	Globigerina ooze	7.1
21 04 S	133 01 W	4069	Calcareous mud	22.2
10 38 N	105 47 W	3575	Red clay	13.0
24 20 N	24 28 W	5010	Red clay	15.4
24 28 N	149 30 W	4298	Red clay	52.6
2 48 S	152 56 W	4755	Radiolarian ooze	22.8
7 25 S	152 15 W	5030	Radiolarian ooze	50.3
General average.....				17.8

Table 2--Radium in ocean-bottom sediments (Pettersson)

Latitude	Longitude	Depth	Type of sediment	Radium
				$g \times 10^{-12}$ per g
" "	" "	meters		
24 20 N	24 28 W	5011	Red clay	4.3
36 48 S	42 45 W	5305	Red clay	21.9
37 38 N	39 36 W	5303	Red clay	49.6
26 37 N	36 35 W	5382	Red clay	9.3
22 49 N	65 19 W	5413	Red clay	1.5
32 18 N	23 58 W	5422	Globigerina ooze	1.4
30 50 N	27 27 W	5430	Red clay	2.1
14 00 N	30 01 W	5443	Red clay	3.7
25 57 N	35 08 W	5580	Red clay	8.6
43 08 N	19 52 W	5930	Globigerina ooze	4.4
43 05 N	19 41 W	5940	Globigerina ooze	3.3
12 05 N	33 31 W	6035	Red clay	7.8
38 06 S	88 02 W	3537	Globigerina ooze	4.9
13 28 S	149 30 W	4298	Red clay	39.1
3 48 S	152 56 W	4755	Radiolarian ooze	18.3
42 42 S	134 10 E	4755	Red clay	9.6
25 05 S	172 56 W	5304	Red clay	13.1
35 22 N	169 53 E	5303	Red clay	27.2
35 18 N	144 08 E	6629	Red clay	5.4
11 24 N	143 16 E	8184	Radiolarian ooze	8.0
Not given	....	....	Not given	8.9
Not given	....	....	Not given	4.4

Table 2--Concluded

Latitude	Longitude	Depth	Type of sediment	Radium
" "	" "	meters		$\text{g} \times 10^{-12} \text{ per g}$
Not given			Not given	2.2
Not given			Not given	3.9
Not given			Not given	4.3
Not given			Not given	6.7
Not given			Not given	3.0
Not given			Not given	30.3
General average.....				10.96

Table 3--Radium in ocean-bottom sediments (Piggot) collected by Carnegie

Carnegie station	Latitude	Longitude	Depth	Type of sediment	Radium
	" "	" "	meters		$\text{g} \times 10^{-12} \text{ per g}$
6	50 22 N	13 31 W	2604	Terrigenous	1.80
43	2 30 S	95 43 W	3353	Globigerina ooze	7.84
44	3 15 S	99 48 W	3423	Globigerina ooze	5.96
47	14 07 S	111 50 W	3080	Globigerina ooze	3.64
51	29 06 S	114 48 W	2898	Globigerina ooze	5.00
60	40 24 S	97 33 W	4007	Red clay	3.20
62	34 35 S	91 52 W	3610	Globigerina ooze	4.40
63	32 10 S	89 04 W	3393	Globigerina ooze	3.40
64	31 54 S	88 17 W	3879	Red clay	3.96
67	24 57 S	82 15 W	1089	Globigerina ooze	1.92
113	34 44 N	141 04 E	2911	Terrigenous	1.88
115	37 40 N	145 26 E	5396	Terrigenous	4.12
116	38 41 N	147 41 E	5545	Terrigenous	4.76
117	40 20 N	150 58 E	5296	Red clay	7.12
119	45 24 N	159 36 E	5196	Diatom and terrigenous	3.00
127	44 16 N	137 37 W	4026	Blue mud	3.08
128	40 37 N	132 23 W	3806	Red clay	9.60
131	33 49 N	126 20 W	4418	Red clay	5.80
132	31 38 N	128 48 W	4251	Red clay	10.40
133	29 21 N	132 30 W	4426	Red clay	8.96
136	26 13 N	142 02 W	4713	Red clay	9.48
137	24 02 N	145 33 W	5208	Red clay	10.40
149	21 18 N	138 36 W	5320	Red clay	6.04
151	12 40 N	137 32 W	4918	Red clay	21.40
153	7 45 N	141 24 W	5003	Red clay	16.72
156	3 01 N	149 46 W	4953	Red clay	10.92
157	1 48 S	152 22 W	4693	Globigerina ooze	3.96
160	10 54 S	161 53 W	2614	Globigerina ooze	3.88
General average.....					6.52

All these determinations are shown on the accompanying map, which also indicates the character of the ocean-bottom sediment as taken from various publications on oceanography. The diameters of the circles are proportional to the radium-content as reported.

The paucity of these data compared to the vast areas covered by ocean-bottom sediments and these sediments, furthermore, of an unknown depth, render any general conclusions futile.

The most striking fact is the extraordinarily high concentration of radium in these sediments compared to that in ordinary rocks of the Earth's structure. Whereas the average concentration in granites might be placed at about 2.5×10^{-12} gram Ra per

gram of rock, and for basalts at about 1.0×10^{-12} gram per gram, the general average for all these 88 determinations is the astonishingly high figure of 11.76×10^{-12} gram per gram of dry material. Some samples contain considerably more than this, such samples usually coming from the deeper portions of the bottom and those portions more remote from land areas delivering detrital material into the sea.

This high radioactivity is the more astonishing when it is remembered that the sedimentary materials of the continents, even the clays, shales, and limestones, contain less radium than do the igneous rocks.

The geophysical significance of this highly radioactive material depends upon the thickness of these sediments and their history subsequent to being formed. If they are of relatively shallow depth and have not become incorporated into crustal or sub-crustal materials their radium-content is of little geophysical significance; but if, on the other hand, they are of great thickness, and have served to take such concentrations of radium into the structure of the Earth's crust their influence must be considerable, either as blanketing or insulating the flow of heat into the oceans, as is necessary for Joly's thermal cycles, or as providing sources of intense energy for any part of the Earth's crust within which they may become incorporated.

Obviously the elucidation of such questions awaits considerable further research, and the development of some technique which will give some idea of either the thickness of these sediments or the rate of their deposition.

Various mechanisms have been suggested to account for this high concentration of radium, some of which seem to have lost sight of the fact that the significant chemistry involved is the chemistry of uranium and not that of radium per se.

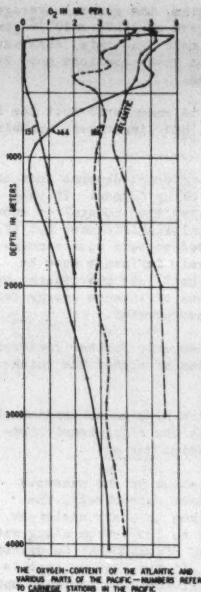
It has been suggested that the concentration is brought about by the numerous minute living-organisms in the sea. These extract, more or less selectively, the salts of uranium and radium from the sea-water, incorporate them in their skeletons, and when they die their remains take the radioactive material to the bottom along with them. In opposition to this reasoning are the calculations of Bischoff that an oyster requires the lime from 76,000 times its weight of sea-water. If the uranium in this bulk of water were taken into the shelly limestones, their radioactivity would be much greater than it is found to be. If the concentration is brought about by sea-organisms one would expect to find some connection between the radium-content and the character of organic remains comprising the sediment. Examination of the tables and the map demonstrates that this is not so. Although a few high figures are associated with globigerina or radiolaria deposits, the red clays, which are predominantly mineral in composition, show more consistently higher radium-contents. If we confine our averages to the more recent analyses we arrive at the figures given below:

27 red clays average 12.1×10^{-12} gram Ra per gram
15 globigerina oozes average 4.1×10^{-12} gram Ra per gram

The uranium in the sea-water must come ultimately from the igneous rocks. It exists in the water in solution, and some process is operating to remove it from this solution and to cause it to accumulate in the bottom-sediments at a concentration considerably greater than in any igneous rock.

The fact that the radium-concentration falls off near shore and there approaches more or less the concentration found in sedimentary rocks, indicates that the process is not one of detrital accumulation or sedimentation. Furthermore, the fact that the higher concentration is found in the red clays, which are assumed to accumulate very slowly, and the minerals of which are thought to be largely formed in place, indicates that the skeletal remains of organisms tend to dilute an otherwise higher concentration.

Pettersson (see pp. 41 and 44 of reference above) does not think that the red clays are rich in uranium per se, nor does he believe that a process of extraction or precipitation from the sea-water is operating, but that these high concentrations are the result of submarine volcanism associated with excessive and rather specialized hydrolytic action at that surface where hot rock and sea-water meet. This explanation



uranium in solution, whereas the very deep bottom-waters far from land do not contain organic material either washed from the land or as undestroyed organisms; consequently they afford an oxidizing environment. That these waters are oxidizing is borne out by the direct measurements of the oxygen-content with depth made by the Carnegie. Typical graphs of these findings by the Carnegie for the Pacific and a graph showing observed data in the Atlantic are shown in the accompanying Figure. This shows that the environment at the bottom of the ocean is almost as oxidizing as at the surface. In the deeper parts of the ocean where there is little movement, the water at the bottom must be at saturation with respect to the oxides of uranium. There is therefore a tendency for them to separate out just as the iron and manganese do. Volcanic dust, detrital material, and skeletons of organisms modify the possible concentration by diluting it.

Thanks are hereby extended to Dr. H.E. Merwin for his helpful cooperation in discussion, advice, and microscopical examinations.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

TEMPERATURE-GRADIENTS IN OCEAN-WATERS

E. B. Stephenson

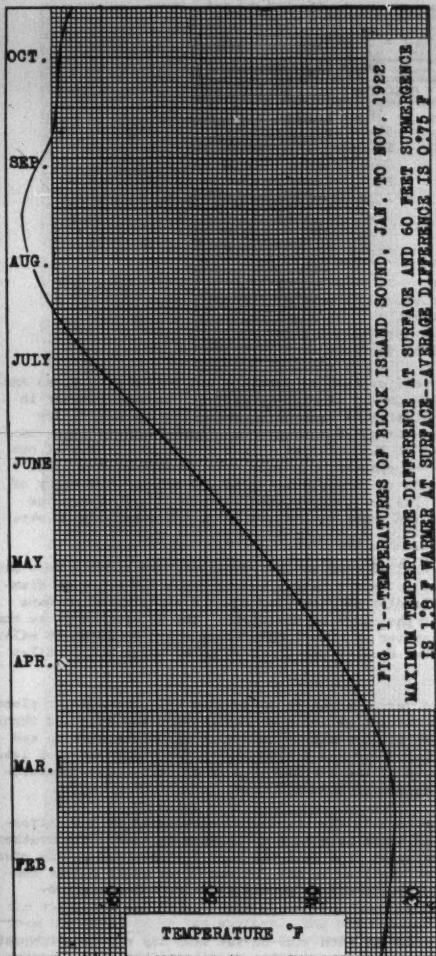
During the past ten years as a part of other work it has been necessary to make temperature-studies of ocean-waters in different areas and under different conditions. It seemed possible that some of the typical results and particularly the technique might be of interest to the Section of Oceanography.

involves a mechanism and sequence of events which seems rather too specialized to account for the observed conditions. It is true that in the two or three core-samples which Pettersson had the good fortune to secure he found a stratified condition with respect to radium-content; but these might be accounted for by differential dilution of a continuing process as well as by sudden and unusual concentration. These observations serve to emphasize again the great desirability of the development of some technique which will produce core-samples for detailed study.

Chemically, uranium, iron, and manganese are similar, in so far as their oxides are among their less soluble compounds, and it is in those portions of the ocean-bottom, in general, where the oxides of manganese and iron are separated, as revealed by the nodules of these elements, that the uranium concentration—as revealed by the radium-content—is the higher.

If we accept the radium-content of sea-water to be 0.02×10^{-12} gram per cc (which is probably too high), which corresponds to a uranium-concentration of 6×10^{-8} gram per cc, we find that the uranium is not greatly different from other well-known metallic constituents such as: SiO_2 , 1×10^{-6} gram per cc; silver, 1×10^{-7} gram per cc; and gold, 6×10^{-10} gram per cc.

There are probably several factors aiding in its separation and concentration in those places where it is found to be most abundant. Skeletal remains may take some down, also dust-particles of volcanic or other origin adsorb some and sweep it to the bottom; but probably the greater proportion comes out as the result of oxidation. That water which is near enough to continents or shallow enough to have sufficient organic material at the bottom to maintain a slightly reducing environment tends to keep its



In making an accurate determination of the velocity of sound in sea-water in 1921 and 1922, it was necessary to know the average temperature and salinity of the working area at the time the velocity-determinations were made. The area was Block Island Sound between Fishers Island and the eastern end of Long Island. These waters vary in depth from 50 to 200 feet. Temperatures were determined with a deep-sea maximum-minimum thermometer lowered from an anchored ship at slack tide at regular monthly intervals and numerous special studies were made at irregular intervals. Readings were made at each ten-foot interval from top to bottom. Figure 1 shows a curve of the average temperatures. The point of interest is that the maximum temperature-difference found at any time between the surface and 60 feet is 1.8 F and the average difference is 0.75 F.

In Table 1 are shown some data taken by the same method but averaged in a different way. On October 9 the upper layer averaged 0.4 warmer than the lower. On October 15 they were the same. On November 8 the upper layer was actually 1.4 F colder than the lower, but by November 28 they had equalized again. The effect on November 8 was due to a cold storm a few days previous. In general this water is thoroughly stirred by surface-winds and by strong tidal currents flowing through The Race in and out of Long Island Sound. This was shown by the close agreement between the average temperatures given in Figure 1 and the readings of a thermometer on the dock at Little Gull Island near the entrance to The Race.

For the past seven years the Naval Research Laboratory has had an expedition at Piney Point, Maryland, near the mouth of the Potomac River. During this period

a large amount of temperature-data has been taken particularly during July and August with the occasional short records in the fall. Until the summer of 1930 it was unusual to find a temperature-difference of more than 1° C between one foot below the surface and the bottom at 50 to 60 feet and in general this difference would be only a few tenths except when there had been a very sudden change in air-temperature. Also the temperatures over considerable areas were remarkably constant. For example, in one survey in August 1929 no temperature-differences vertical or horizontal as large as 1° C were found in an area eight miles by four miles.

Table 1--Temperatures in Block Island Sound,
one mile south of Fisher's Island

Date	Mean temperature	
	0-50 feet	50-100 feet
1931	°F	°F
Oct. 5	61.0	.....
9	59.1	58.7
10	58.8	58.3
15	57.7	57.7
16	58.1	58.2
17	57.8	58.0
Nov. 8	52.1	53.5
28	49.4	49.4

Notes--Data taken with a deep-sea maximum-minimum thermometer lowered from anchored ship at slack tide; depth of water about 125 feet; strong tidal currents

In 1930 at Piney Point larger differences between top and bottom were found and in 1931 these differences were occasionally as much as 2.5 C. The temperatures in 1931 were also generally higher. It will be remembered that 1931 was a very dry spring and summer and one would have expected the water at Piney Point to be unusually clear but on the contrary it was so full of small plant and animal life that one could see only a few feet through the eyeport of a submarine at submergence of 40 feet. There is a correlation between the temperature-gradient and the turbidity of the water here and in later data. The suspended particles scatter and absorb the light transforming it into heat in the upper layers and largely prevent its penetration to the deeper layers.

In January, February, and March 1931 some extensive temperature studies were made in the Panama Bay area. Panama Bay is approximately a semicircle 100 miles in diameter with the eastern end of the diameter at Pinas Bay and the western end at Cape Mala. Panama City is at the top of the curve on the north. The 100-fathom curve runs east and west roughly along the diameter and the 1,000-fathom curve is 20 to 30 miles to the south. The Perlas Island area studied was about 30 miles south and 10 miles east of Panama City.

Figure 2 shows the temperature versus depth as determined by a thermometer placed outside a forward eyeport in the conning-tower of a submarine underway at about three knots. Readings were normally taken at five-minute intervals at constant depth and more frequently when changing depth. There was a time-lag in the thermometer of less than one minute after a sudden change of temperature of 3 C or more. The pressure-effect on the thermometer was negligible down to 200 feet.

The curves show radical differences in the temperature-gradients in the different places. It should be noted that there is also a difference in time. The weather was generally hot and calm. The water at Cape Mala was much clearer than at the other two places. This confirms the effect noticed in the Potomac River where a high concentration of living organisms was seen to aid in producing a large temperature-gradient.

Figure 3 shows the change in gradient with time on the same day and on different days at approximately the same place though it must be remembered that the submarine is underway at about three knots and the place is not exactly the same. This shows clearly on the curve for February 5 where the temperature rose about 2.5 at a constant depth of 70 feet.

Figure 4 shows some of the data on February 5 where temperatures are plotted against time.

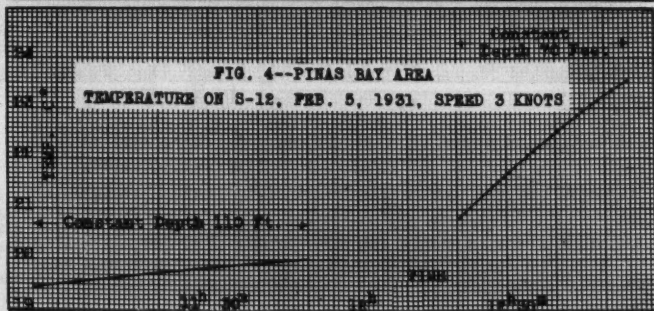
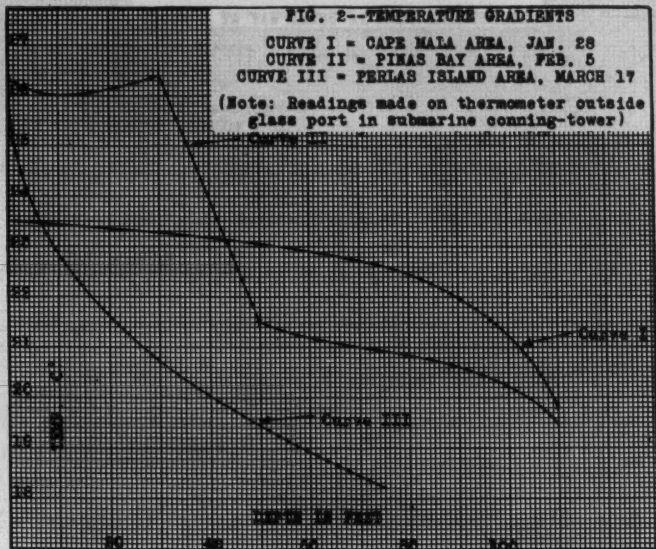


Figure 5 shows a comparison of the temperatures obtained with a thermometer on the submarine and with a special quick-acting platinum-resistance thermometer lowered from the Eagle 58 on the surface. The thermometer and leads were lashed to a 75-pound sounding-lead. Readings were made going down and coming up. A precision-bridge and galvanometer made the device sensitive to 0.01 C though it was difficult to get a balance closer than 0.1 C. The electrical thermometer misses the sudden drop between 30 and 50 feet and at 50 feet is 5° too high. The explanation probably lies in the fact that the Humboldt Current comes up strong and cold from the south and when the sounding lead struck this Current it was carried out horizontally although at the surface it appeared to go down vertically. The strength of this Current is indicated by one experience on the submarine where we ran north for two hours making turns for three knots submerged at 50 feet, turned around and ran south for four hours, and came up north of the starting point.

FIG. 3--PINAS RAY AREA
TEMPERATURE ON S-12 UNDER WAY AT 3 KNOTS

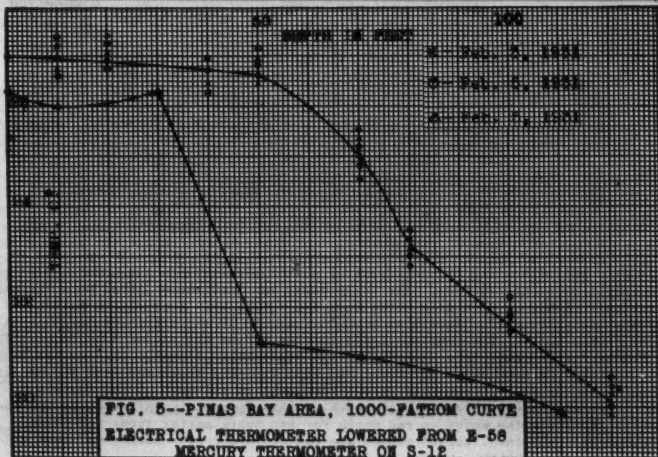
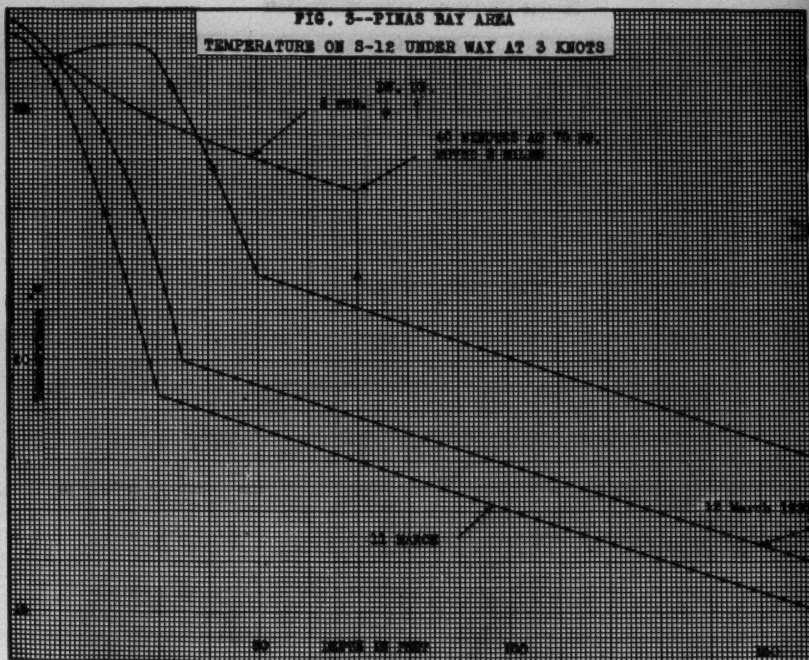


FIG. 5--PINAS RAY AREA, 1000-FATHOM CURVE
ELECTRICAL THERMOMETER LOWERED FROM E-56
MERCURY THERMOMETER ON S-12

Table 2 shows some data taken on the U.S.S. *Nautilus* near San Clemente Islands off San Diego, California. These gradients are very small compared with those at Panama and are consistent on successive days.

Table 2--Temperatures taken on U.S.S. *Nautilus* near San Clemente Islands

July 14, 1931			July 15, 1931		
Time	Depth	Temp.	Time	Depth	Temp.
h m	meters	°C	h m	meters	°C
15 10	1	22.7	14 45	1	22.0
16 15	50	22.2	14 55	50	21.5
15 30	100	22.2	15 10	100	21.5
15 50	150	22.0	15 30	150	21.0
Air-temperature		25.5	Air-temperature		28.5

Dr. Meinezev very kindly took temperature-readings on the S-48 during his gravity-survey in the spring of this year and two typical series of readings are shown in Table 3. The maximum difference found between 40 and 100 feet at 20 different stations was

Table 3--Data taken by Dr. Meinezev on gravity-survey

Location	Depth	Temp.	Location	Depth	Temp.
	meters	°C		meters	°C
North of Haiti	32	25.2	125 miles east Miami	40	23.8
22° 02.5 N	42	25.1	26° 10.5 N	70	23.9
72 30 W	70	25.0	78 11 W	70	24.0
	90	24.8		100	24.0
	100	24.7		70	24.0
	125	24.7		40	23.9
	150	24.6			
	125	24.7			
	100	24.9			
	70	25.0			
	50	25.2			
	42	25.2			

Notes: Thermometer mounted outside conning-tower and read through forward eyeport; maximum difference between 40 and 100 feet in 20 locations was 0.5 C while 10 stations showed 0.0 difference.

0.5 C and ten stations showed no difference. The initial depth of 70 feet was maintained for about 40 minutes and in no case did the temperature change by more than 0.2 C in marked contrast with the 2.4 change in same time and at the same depth in the Pinas Bay area in 1931. It should be noted that Dr. Meinezev's data all begin at 30 to 40 feet and that it is between 0 and 40 feet that the relatively high gradients are found.

Probably the most important conclusion to be drawn from these data is that broad generalizations about temperature-gradients should be made with caution and only after elaborate studies. If one wishes to know the exact gradient it must be measured at that particular time and place. There is a close correlation between the temperature-gradient near the surface and the concentration of light-absorbing material in the water.

From the point of view of technique the submarine furnishes a new method that is simple, precise, and rapid and it would seem quite practical to develop analogous methods for obtaining simultaneous data on temperature, pressure, salinity, light-absorption, and scattering, and the collection of samples down to depths of 200 feet.

U. S. Naval Research Laboratory,
Bellevue, Anacostia, D. C.

PROGRESS IN THE INVESTIGATION OF SURFACE-TEMPERATURES OF
THE WESTERN NORTH ATLANTIC

Phil E. Church

From the mass of accumulated thermograph-records made on commercial vessels came the task of making an accurate appraisal of the temperatures, including the thermal pattern and the fluctuations of temperature within the rough triangle of the North American Coast limited on the east by a line from Halifax to Bermuda and on the south by the 30th parallel. The records from January 1929 to May 1931 were used, during which period the frequency of the thermograms over the various routes was sufficient to allow the construction of numerous synoptic charts of the surface-temperatures. In all, 36 charts were made, each being drawn from the records made within a week's time. At least two thermograms made over routes close together were necessary for each chart--most of them had three or four and some had five. From these data isotherms were drawn at a 3-degree Fahrenheit interval for the eight months with the coldest temperatures and at a one-degree Fahrenheit interval during the four warmest months.

The charts clearly show five, and perhaps six, areas distinctly set apart from one another by certain characteristics of surface-temperatures. A line from New York to Bermuda would cross in turn (1) the coastal water, (2) a cool area, (3) an upwelling zone, (4) the cold wall --along its edge of coldest water is the upwelling zone, (5) a ribbon of hot water commonly called the Gulf Stream, (6) a wide, warm area. In view of the fact that the temperatures of the water to the north are somewhat dependent on those of the Gulf Stream, the areas will be discussed in reverse order, that is, from south to north.

The warm area

Though it lies in lower latitudes the warm area is somewhat cooler in all seasons of the year than is the Gulf Stream. This condition is ascribable, in part, to the lack, or very slow drift, of an incoming supply of warmer water such as feeds the Gulf Stream. Also the homogeneity of the temperatures is striking. From its northern limit to the 30th parallel the temperatures, for the most part, rise slowly but consistently. In late winter the central part has the coolest temperature. Only at rare intervals, most frequent in Spring, is there any evidence of alternately warmer and cooler masses along the zone contiguous with the Gulf Stream. Of the thermograms examined which represented 342 crossings on three routes only 59 showed the presence of secondary bands which differed 3° or more. The difference between the highest and lowest temperatures within the area at any time rarely exceeds 5° and more often is only 3° or 4°.

Table 1 gives the maximum and minimum temperatures found within the area for each month of which one or more charts were made. The remarkable consistency of temperatures from year to year can readily be seen.

The mean annual range of this water is about 17°, namely, from 65° F to 82° F, and in different years does not vary from these figures by more than 2° or 3°. The maximum is reached apparently in August or early September and the minimum in the latter part of March or early April. There is a considerable lag of the maximum and minimum behind the highest and lowest positions of the Sun. The whole area, however, warms and cools simultaneously.

The greatest departure from its average temperature was in December 1930 and the following four months of 1931. In this period the water was consistently about 2° cooler than in the corresponding months of the preceding years.

The "ribbon of hot water"

The "ribbon of hot water," marking the Gulf Stream, was found to be narrower than formerly supposed. Southeast of Cape Hatteras the charts show this ribbon of hot water to be about 50 miles wide, on the average. It gradually widens toward the east, but still remains quite narrow, for south of Nova Scotia it is but 70 miles wide, on the average.

Table 1--Surface-temperatures of the western North Atlantic, January 1929 to May 1931

(MP = south of Montauk Point; H = south of Halifax; OCP = off Cape Hatteras; N = south of Nantucket; NY = south of New York; O = no upwelling zone; .. = no data)

Region and year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Warm area	*F	*F	*F	*F	*F	*F	*F	*F	*F	*F	*F	*F
Minimum 1929	68	66	65	85	..	72	77	..	79	75	73	71
1930	69	67	..	67	68	75	77	79	79	75	73	69
1931	67	64	64	65	..	..	..	..	..	..	..	..
Maximum 1929	73	72	70	73	..	75	80	..	83	78	78	76
1930	74	71	68	72	78	77	81	83	84	79	78	73
1931	73	68	67	70	..	..	..	..	..	..	..	..
Gulf Stream												
MP 1929	76.0	77.0	72.5	76.6	..	79.2	82	..	83.9	78.1	79.2	79.5
Week 3	8	11	16	16	..	23	29	..	36	42-43	47	50
1930	77.0	76.1	73.5	76.0	77.3	81.0	83.0	83.6	85.0	81.0	79.9	76.0
Week 2	8	12-13	16-17	20	25	28	34-35	38	41	47	50	
1931	74.1	72.0	71.8	74.0	..	..	..	..	..	..	..	..
Week 3	8	12-13	16	..	..	..	..	..	..	..	..	..
H 1929	75.0	73.2	69.1	75.2	..	..	..	..	81.9	76.8	..	76.5
1930	76.9	74.5	..	..	78.0	..	82.2	82.4	80.1	..	..	..
1931	..	..	..	..	..	..	..	..	..	..	..	..
Cold wall												
OCP Min. 1929	56	64	52	60	..	64	76	..	80	71	63	60
1930	60	56	51	61	67	73	76	73	75	71	62	52
1931	44	44	44	61	..	..	..	..	..	..	..	..
Max. 1929	76	77	72	76	..	79	82	..	84	78	79	79
1930	77	76	73	76	77	81	83	83	85	81	79	71
1931	74	72	71	74	..	..	..	..	..	..	..	..
H Min. 1929	58	55	46	63	..	..	..	..	73	58	..	55
1930	57	55	..	..	70	..	77	72	70	..	..	..
1931	..	..	..	..	..	..	..	..	..	..	..	..
Max. 1929	73	73	69	75	..	..	..	..	82	76	79	76
1930	76	74	..	..	78	..	82	82	80	..	..	..
1931	..	..	..	..	..	..	..	..	..	..	..	..
Upwelling zone												
1929	MP	N-MP	H-N-MP	MP	..	N	N	..	O	O	H	N-MP
1930	O	O	H	H	..	H	O	..	MP	MP	N	O
1931	O	N	H-MP	H	..	..	..	..	..	..	..	..
Cool area												
Minimum 1929	49	40	36	35	..	63	74	..	64	57	60	45
1930	39	40	45	49	45	69	65	65	67	71	80	56
1931	50	45	51	48	..	..	..	..	..	..	..	..
Maximum 1929	64	60	67	53-71	..	72	79	..	79	72	66	69
1930	69	69	67	64	70	74	79	76	77	72	68	65
1931	62	53	55	57	..	..	..	..	..	..	..	..
Coastal water												
NY Min. 1929	37	36	37	44	..	58	69	..	70	56	52	40

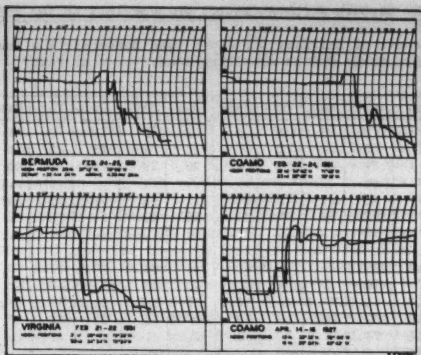


Fig. 1--Portions of four thermograms showing temperature-profiles during April (Courtesy Geographical Review, American Geographical Society of New York)

the "ribbon of hot water" when it is pinched off by the cooler wedge and the Gulf Stream continues its flow on the more southerly track. This splitting of the Gulf Stream with the elimination of the warm northerly projection causes wide temporary migrations of the Gulf Stream within a short period. These fluctuations increase in magnitude to the east. It is notable that these migrations, in the longitude of Halifax, have brought the southern edge of the Gulf Stream farther north than the mean position of the northern edge or "cold wall," and also the northern edge of the Gulf Stream has been pushed farther south than the mean position of the southern edge. South of Halifax the northern edge of the Gulf Stream has been within 230 miles of the coast and as far as 420 miles, though its average position is only 290 miles distant. When these migrations occur the southern edge respectfully remains within 50 to 70 miles of its northern companion.

There is but slight indication of a definite seasonal cycle in the course of the Gulf Stream.

In an article in the *Geographical Review* (Apr. 1932, v. 22, pp.286-293), I stressed the fact that the Gulf Stream as a definite body of water is distinctly set off from the water on either side. On both sides of this tropical water occurs a sharp change in temperature, the greater, of course, being at the northern edge or "cold wall." The southern edge is a very definite zone marked by a change of from 2° to 5°. An inspection of the thermograms (Fig. 1) clearly portrays this edge.

In its flow from southwest to northeast the Gulf Stream gradually cools. On the average, in the longitude of Halifax, the maximum temperatures are about 2.5 lower than those near Cape Hatteras in winter, and in summer about 1° to 1.5 lower. This decrease in temperature is due primarily to the length of time necessary to make the long journey. Cooling is more rapid in winter than in summer owing to the lessened insolation, increased net radiation, and the greater contrast of air and surface-water temperatures. The small decrease in temperature is primarily due to the large volume of incoming highly heated tropical water. The annual range of temperature, therefore, is small. Off Cape Hatteras this range amounts to about 11°, from 74° F to 85° F, at the temperature-axis. South of Halifax the range is increased to about 13°, from 69° F to 82° F. From these average figures the Gulf Stream may vary somewhat, as much as 3° or more, though a departure this large is more apt to occur with the lower temperatures of winter than with the higher ones of summer.

In the annual march of temperature the minimum is reached in late February or early March and the maximum in early September. It is interesting to note from the

During the colder half-year, when the water of the north presents a sharp contrast in temperature to that of the Gulf Stream, offshoots of the warm tropical water appear to detach slowly from the parent mass and move as eddies or projections into the cooler water to the north. Such is a frequent occurrence in winter, but in summer, with the lessened contrast of temperature, this action is less marked.

Occasionally these warm offshoots or projections are fed for such a length of time--a month or six weeks--that their surface-temperatures become nearly as high as those of the more southerly source. A wedge of cooler water separates these two warm bodies, giving the Gulf Stream and its northern projection the shape of a Y lying on its side. The northern projection becomes separated from

table that the temperatures of December, 1930, and the following four months of 1931 were consistently from two to 4° cooler than in the two previous years. This coolness in the Gulf Stream came at the same time as that in the warm area, already mentioned. Though the departure was greater for the Gulf Stream it appears likely that a departure in temperature of the Gulf Stream may be a guide to the departure of the wide, warm area. Probably the warm area, because of its greater area than the narrow Gulf Stream, has a far greater influence on the climate of the eastern seaboard than does the Gulf Stream.

The "cold wall"

From time to time one hears of remarkably great contrasts in temperature within a short distance along the northern edge of the Gulf Stream. The most frequently cited example is the case of a difference of 22° within 240 feet between bow (34° F) and stern (56° F) of the Coast Guard Cutter *Tampa*. From the thermograms it was found that the average rate of change amounts to about one degree per mile. Even this is an extremely steep temperature-gradient for ocean-temperatures.

This average condition is modified considerably depending on the conditions obtaining, at times becoming steeper and at others flattening out. Often there may be a change of only a few degrees within 50 or 60 miles and again there may be a 30-degree change within five or ten miles. Some of this irregularity is the result of the seasonal temperature-change of the water on either side, particularly the water to the north, but most is owing to the projections or eddy-detachments of warm water which apparently break through the "cold wall." At the front edge, or the retreating edge, of one of these projections the "cold wall" shows a moderate temperature-gradient when the ship's course is nearly parallel to the isotherms.

The "cold wall" attains its maximum development when the greatest difference in temperature exists between the cool waters to the north and the hot water of the Gulf Stream. This comes during March or even early April and has resulted in differences as much as 30°. The average difference within this zone in late winter, however, seems to be in the neighborhood of 20° to 22°. By June the cool water to the north of the "cold wall" has warmed to such an extent that there is an abrupt change of only 12°. This is further reduced during the period of maximum temperatures, late August or early September, for the "cold wall," though still abrupt, has dwindled to a change of only 6° or even less.

The upwelling zone

Between the "cold wall" and the cool water to the north is a narrow band, not more than a mile or two wide in most cases, of water cooler than that on either side, which exists only under certain favorable conditions. As the temperatures are lower than those to the north, often not being matched within 40 to 100 miles, it is assumed that the water comes up from below. Hence, I have chosen to call it the upwelling zone. It may be considered as a part of the "cold wall." With the single exception of August, this zone has occurred in all months, but is less marked from May to October than during the other months.

This zone is best developed when the "cold wall" is most marked and the temperature-gradient to the northwest is even and regular. When an eddy or projection moves out from the Gulf Stream the normal course of the "cold wall" is disturbed and deflected to the left. This reversal from the normal sweep of the Gulf Stream to the right seems to spell the death-knell for upwelling. In the most extreme cases the lowest temperatures may be as much as 5° to 8° lower than those immediately to the north.

The cool area

Between the edge of the continental shelf at the 100-fathom line and the upwelling zone or "cold wall," is an area, roughly triangular in shape with the apex at Cape Hatteras, which is characterized by ever-changing temperatures which are quite in contrast to those of the warm area south of the Gulf Stream. Heterogeneity of temperatures singularly sets off this portion of the Atlantic from the other areas. Large monthly and seasonal fluctuations in different parts of this body are the rule, whereas homo-

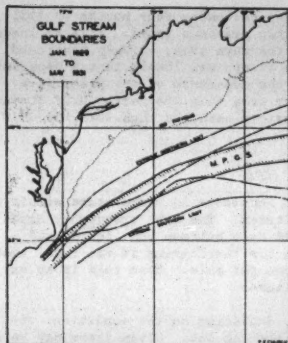


Fig. 2—Mean position and extreme migrations of both edges of "ribbon of hot water" (Gulf Stream), period January 1929 to May 1931 (Courtesy Geographical Review, American Geographical Society of New York)

geneous temperatures are the exception. The large fluctuations are the result of the advance and passing of warm projections or eddies from the Gulf Stream.

The frequent occurrence of masses of Gulf Stream water in this area makes it difficult to determine the mean annual range and the monthly changes. However, there is a general warming in late spring and early summer and an analogous cooling in late fall and early winter. The minimum and maximum temperatures vary considerably each year, both as to the time of arrival and the degree.

Extremes of temperature in any one month may be large, as in April, 1929, when there was a difference of 37° from the warmest to the coldest (72° F to 35° F) within the area. Conditions change rapidly within a few months, however, to a small difference, as in July of the same year, when the difference amounted to only 5° (78° F to 73° F). In February, 1930, in the western part, an even and regular temperature-gradient attended a difference of only 16° from the warmest to coolest parts. In the summer of 1930 differences were small.

The presence of warm masses which invade this area from the Gulf Stream has been mentioned. But what causes this interdigitation of warm and cold water? What causes this branching or splitting of the Gulf Stream? Is it due to the atmospheric storms with high wind-velocity which may detach large masses of water and blow them far to the northeast? If so, why are not warm masses found south as well as north of the Gulf Stream? In the winter when the northwest wind is strongest these masses are far more prevalent to the north of the Gulf Stream than to the south of it. These masses appear to move northeastward at right-angles to but to the left of the prevailing northwest wind, whereas the motion should be to the right in this hemisphere if the masses were wind-driven. Thus it appears that these masses at this time of the year, at least, can not be wind-driven.

A more plausible explanation of their origin seems to lie in eddy-formation along the zone of contact between the cold waters to the north and the hot water of the Gulf Stream. These two bodies of water differ in direction and speed of motion as well as in temperature. The eddies or projections seem analogous in nearly all respects to atmospheric lows. The water-eddies or projections apparently pass through the same stages of generation, development, and occlusion as the atmospheric lows, though at a much slower speed.

Undoubtedly the whole explanation of the formation of these warm masses from the Gulf Stream debouching into this cool area can not be derived from surface-temperature alone, but this possible explanation may be used as a working hypothesis. The explanation of the presence of these warm masses in this area must await results of much research, not only surface-temperatures, but sub-surface temperatures, salinities, velocities and directions of current, and the weather over the western North Atlantic.

The coastal water

Of the various areas the coastal water has the only definitely fixed boundaries. It may be regarded as the water lying over the continental shelf as far out as the 100-fathom line. It is also the area having thermograph-data covering the least portion, for, with the exception of the Canadian National vessels which sail from Halifax or St. John, New Brunswick, all records have New York as a terminus. This has limited the study of surface-temperatures to two narrow and widely separated zones south of these ports. Data are not lacking between these zones, though they are not automatically

recorded, for the Bureau of Fisheries vessel Albatross II notes the surface temperatures at all of the numerous stations made during the season of mackerel and haddock cruises.

Vessels sailing from New York are in the coastal water for a comparatively short time except those which make the Diamond Shoals Light-vessel from New York.

Several factors combine to give this area a large annual range and wide monthly changes. The water is comparatively shallow; it lies, in general, in somewhat higher latitudes than the others and is more subject to the direct effect of continental winds and their extremes, especially in winter. Owing to these factors monthly changes of as much as 8° or 10° are not uncommon. The mean annual range, south of New York, is nearly 40°, from near the freezing-point to 70° F, or slightly higher. This area has less seasonal lag than the others for it follows more closely the insolation and the temperatures of the land.

Summary

For the first time the "ribbon of hot water," called the Gulf Stream, is shown to be an invariable characteristic during all months. The Gulf Stream is sharply set off from its bordering waters by abrupt changes of temperature. Also, there is the remarkable irregularity of warm and cold water interdigitation, north of the Gulf Stream, present, especially during the colder half-year. The warm projections appear to be eddy detachments from the warmer parent mass of the Gulf Stream. At varying intervals the Gulf Stream makes wide temporary, northerly migrations when a warm projection is fed by the newer tropical water until the temperatures closely approach those of the main body farther south. Sooner or later a cold wedge pinches off the source of warm water and the Gulf Stream continues its flow in a more southerly position. Wide temporary migrations have thus occurred. There is little indication of any definite seasonal shift.

The "cold wall" is present throughout the year though the contrast in the warmer half-year is considerably less than that during the colder half-year. Temperature changes of as much as 30° may occur within a few miles in late winter.

The chief characteristic of the cool area is the heterogeneous temperature-distribution owing to the presence of temporary projections from the Gulf Stream. Large ranges of temperature in any one place result from the general northeasterly drift of these masses.

The shallow coastal water displays the greatest annual range of surface-temperature of any of the subdivisions.

South and southeast of the Gulf Stream is the wide, warm area of the homogeneous temperatures, a few degrees cooler than the "ribbon of hot water" that skirts its northern edge. A relatively large departure from the normal temperatures of the Gulf Stream is possible, this departure appearing as a probable index of departure of surface temperatures of the wide expanse of the warm area.

Clark University,
Worcester, Massachusetts

THE RECOMMENDATION OF A PROGRAM OF HYDROGRAPHICAL OBSERVATIONS LEADING TO THE QUANTITATIVE DETERMINATION OF ARCTIC AND ATLANTIC INTERCHANGES

E. H. Smith

A communication recently received from the President of the Commission of the Second Polar Year, for the International Council for the Exploration of the Sea, with enclosed copies of correspondence, indicates that in conjunction with the already approved program of observations for the International Polar Year, efforts are being made to carry out a plan of concerted oceanographic investigations.

The International Council for the Exploration of the Sea at its meeting in March, 1931, recommended that all members concentrate efforts on northern sea investigations during the Second Polar Year, 1932-33.

The Committee of the Union of Socialist Soviet Republics has already approved a program of oceanography for that country during the Polar Year. A description of this proposed work has been forwarded to the President of the Commission of the Second Polar Year, 1932-33, urging that other countries, parties to the Polar Year Commission, establish as quickly as possible similar programs of hydrographic work. The international Council for the Exploration of the Sea now inquires what can be expected of each member country during the Polar Year: (a) In sectors of interest to Soviet Russia; (b) in other parts of the open sea; (c) along the routes and polar sectors assigned to each country for meteorological and magnetic observations under the original program of the Polar Year.

One of the most important questions which the synchronized observations of the Second Polar Year program hope to explain, is the cause of the well-known atmospheric interactions which attain polar to temperate-zone amplitudes. These continual fluctuations in behavior of the polar front of the atmosphere never can be predicted unless a contemporary study is also undertaken of similar phenomena in the hydrosphere. Assuming that oceanic temperature-variations are initiated by variations from normal in the distribution of atmospheric pressure (conclusions of Helland-Hansen and Nansen in *Temperature-variations in the North Atlantic Ocean*, and in the atmosphere, *Smith. Mis. Coll.*, No. 4, Washington, 1920), once a given body of water is warmed or cooled to an abnormal state, it will maintain such a value, by reason of specific heat, for an appreciable elapse of time. It is easy to understand, therefore, why masses of abnormally warm water may be found abnormally far poleward in an ocean-basin, and vice versa.

The occurrence of irregular variations from a normal system of oceanic circulation have often been proved by actual field observations. In the summer of 1931, the Coast Guard patrol boat *General Greene* repeated a detailed hydrodynamic survey of Davis Strait, previously made by the patrol boat *Marion* in the summer of 1928. A comparison between the two isobaric maps for 1,500-decibar surface shows quite plainly that the Labrador Current occupied different positions in the two years. But more striking is a comparison between the Cape Farewell to Newfoundland hydrographical sections of the two surveys. Much saltier and warmer water filled the Greenland half of Davis Strait in 1931 than in 1928. The presence in this region of such a great additional amount of heat must necessarily have affected the surrounding atmosphere in 1931 quite differently than in 1928. Not until the hydrophysical surveys of the *Marion* and the *General Greene* had been compared, however, was it realized that variations of such magnitude take place in the oceanic trough between Labrador and Greenland.

The effect on the atmosphere of variations in the normal thermal state of the North Atlantic Ocean has been proved by Brooks and Quennell in their investigation of the relation between Arctic ice and European weather (The influence of arctic ice on the subsequent distribution of pressure over the eastern North Atlantic and western Europe, *Met. Comm., Air Ministry, Geophys. Mem.*, No. 41, London, 1928). More ice than normal off Iceland causes in the same months an excess of atmospheric pressure from Paris to the Azores. A greater area of ice than normal during spring and summer in northern waters is liable to be followed by a deficiency of atmospheric pressure the following autumn around the British Isles. The cause lies in the liberation of more cold water than normal by melting of the ice to mix with the Gulf Stream Drift during the summer, and such regional variations in sea-temperature produce corresponding thermal and barometric variations in the atmosphere bringing stormy weather to northern Europe.

Since atmospheric variations of major proportions, therefore, are often the reflection of variations in the volume of the ice and the cold water discharged from the Arctic, any circumpolar study of the weather as embraced by the program of the Second Polar Year, most certainly, ought to include contemporary hydrographical observations.

The most useful oceanographic information in conjunction with a detailed study of polar weather-maps would be monthly mean isothermal maps of the upper 200-meter surface-layer of the ocean north of latitude 40° north. Such data, when compared with

an established normal for that particular period and expressed as isonomalies, would furnish the very best possible means of determining a correlation between hydrosphere and atmosphere. It being physically impossible, however, to collect such a stupendous mass of observations, the most practical plan consists of taking frequent hydrographical sections across the principal warm and cold currents. If such sections be repeated in successive years, we shall soon accumulate a very valuable record for comparisons.

The oceanographic program which Soviet Russia intends to carry out during the forthcoming Polar Year consists of several vertical sections extended north and south in the Barents Sea, and cutting more or less at right-angles across the cold and warm currents. It is also planned to repeat the sections every four months during the Polar Year. Other critical points where it has been suggested that sections be made periodically are: (a) England-Iceland-Greenland; (b) Spitsbergen-Greenland; (c) Bering Strait; and (d) Davis Strait. The southern currents likewise are recommended for measurement, namely, (a) Florida Strait; (b) Hatteras-Bermuda; (c) Grand Bank-Sargossa Sea; (d) east and west sections in the eastern North Atlantic. In addition the Soviet government plans to make special efforts to record the volume and extent of ice discharged into the northeastern North Atlantic during the period 1932-33. Similar studies are recommended for the east Greenland and Labrador ice-discharges, by the Union of Socialist Soviet Republics, following the methods which have been in use by the International Ice Patrol off Newfoundland.

In order to stimulate interest and efforts in a program of oceanographic investigations cooperative with that already planned for the Second Polar Year, there is described here some of the quantitative measurements which the Ice Patrol has been making with regard to the discharge of ice and cold water into the western North Atlantic Ocean. The experience gained from this work can be wisely employed in arranging a program for the Second International Polar Year.

Since its inauguration in 1913, and augmented by records dating to 1900, the Ice Patrol has made a careful count of the actual number of icebergs per month which drift south of Newfoundland (the 48th parallel of latitude). The annual amounts of arctic ice in the western North Atlantic since 1880 have also been adapted to the Ice Patrol records, furnishing for correlation a long series of 60 years. Great variations in the volume of arctic ice discharged into the western North Atlantic have occurred, ranging from a minimum of no ice south of Newfoundland in 1931 to an outburst of 1,330 icebergs in 1929. The iceberg-forecast for the present year is a number somewhat less than normal. Ice-records kept for the other principal points of arctic discharge, the east Greenland Current, although not in such great detail, show equally clearly that the ice is subject to marked annual variations.

An investigation of the effect of northern ice, both sea and land, on the temperature and circulation of the waters of the North Atlantic Ocean (Edward H. Smith, The Marion Expedition to Davis Strait and Baffin Bay under the direction of the United States Coast Guard, 1928, Scientific results, Part 3, Bull. 19, Washington, 1931), as contained in the recently published report of the Marion Expedition, express for the first time, to my knowledge, these large-scale phenomena in quantitative form.

- (a) The North Atlantic Ocean is cooled annually by arctic ice to a degree equivalent to one-half the summer's warming by the Sun.
- (b) The cold currents' discharge into the North Atlantic Ocean has approximately ten times the cooling effect that is possessed by the annual melting of arctic ice.
- (c) The water which is discharged out of the arctic into the North Atlantic, with varying volume from year to year, is not cold because of the arctic ice, but because of the low air-temperatures of the polar regions.

The researches of the International Ice Patrol show, therefore, that the ocean-currents are the major controls of the thermal state of an ocean, while drifting ice, as a cooling factor, is quite secondary. Thus it may be concluded that undue significance has been attached to the reports of great outbursts of ice from polar regions, except in instances when the cold currents have also swelled in unison with great ice-invasions. That cold current and ice do not always vary together, has been shown by our observations. For example, in 1931, when the Labrador Current indicated a normal

volume, the number of icebergs were nil. As a cooling agent alone, drifting polar-ice has relatively little far-reaching effect. Another common fallacy concerns icebergs, which particularly catch the imagination, yet according to our studies, constitute only two per cent of the total drift-ice of the Labrador Current.

As a result of the foregoing, it may be safely stated that the most accurate index of the ever-varying cooling effect of the arctic is contained in periodic measurements of the cold currents. The most valuable observations of the Ice Patrol, in this respect, consist of a series of hydro-dynamic surveys of critical sea-areas, repeated for several years, and in accordance with Bjerknes' formulae of hydro-dynamics. But quantitative determinations on the flow and heat-content of an ocean-current can be obtained, however, by one simple vertical section wisely placed.

The International Ice Patrol has found that the volume of discharge of the Labrador Current at the Tail of the Grand Bank varies from a maximum of 5,000,000 tons per second to 800,000 tons per second. This capricious Current not only exhibits the foregoing seasonal fluctuations during the course of the year, but also is subject to irregular pulsations of shorter duration. Such pulsations, as a rule, however, are attributed to the local banding of the Current--accelerating as it narrows, and retarding as it widens--with little alteration in the total volume of flow. The annual mean volume of discharge of the Labrador Current off the Tail of the Grand Bank, into the side of the Gulf Stream, is approximately 3,000,000 tons per second, with a mean temperature of 37° F.

The Marion Expedition measured the rate of flow across the main trunk of the Labrador Current opposite Hamilton Inlet in July, 1928. The dynamic heights of eight stations spaced at regular intervals, for a total distance of 120 miles, out across the continental shelf, when calculated by Bjerknes' formulae, gave a total mass-flow of 10.5 million tons per second. No information is available as to the quantitative variation of the main trunk of the Labrador Current due to the lack of year-round observations.

Last summer, the United States Coast Guard, the service charged with the operation of the International Ice Patrol, sent its oceanographic vessel, General Greene, to repeat the hydro-dynamic survey of Davis Strait, first made by the Marion in 1928. Attention in this respect is drawn to the importance of again repeating the survey of this sea during the Polar-Year summers of 1932 and 1933.

A cooperative program, moreover, of similar hydrographical surveys, one during each summer of 1932 and 1933, is highly desirable for the other area in which occur Atlantic and Arctic mixings, namely, along the front, Spitsbergen to Cape Farewell, Greenland.

In addition to such a summer-time regional survey, a year-round quantitative determination of the volume of arctic and tropical interchanges is indicated in conjunction with the Second International Polar Year. A minimum amount of work is contained in vertical sections repeated quadri-annually across the two Arctic-Atlantic channels, (a) Newfoundland-Greenland and (b) Shetland-Faroes-Iceland-Greenland.

U. S. Coast Guard,
Washington, D. C.

OCEANOGRAPHIC WORK OF THE UNITED STATES COAST GUARD DURING 1931 AND PLANS FOR 1932

N. G. Ricketts

Three vessels were detailed to the International Ice Patrol duty in 1931 by the United States Coast Guard instead of two as formerly. It was planned to have the Mojave and the Pontchartrain, the two larger vessels, remain with the southernmost ice-limits southeast of Newfoundland primarily to gather ice-information and to disseminate same to shipping. The third vessel, the 125-foot patrol boat General Greene carried all the ice patrol & oceanographic equipment and was to be used mainly for the scientific program.

On March 18, 1931, the General Greene left Boston, Massachusetts, for the ice-regions with orders to find the southernmost ice-limits and to report when the ice-

of the two larger vessels would be needed to inaugurate the continuous ice-patrol service. The year 1931 proved to be one of extraordinarily light ice. No ice menaced the United States to Europe steamship lanes, and the larger ice-patrol vessels were never called upon to leave United States waters.

During the spring, therefore, the brunt of the 1931 ice-patrol scouting and radio service fell upon the General Greene. Only 18 oceanographic stations were taken during the first part of the season. By June 19, after it was definitely established that the ice-menace to the shipping lanes was over, the ship was devoted to the oceanographic program. From June 19 to 29 a cruise was made during which 54 oceanographic stations were occupied on the northern, eastern, and southern slopes of the Grand Banks to determine the dynamic circulation.

From July 4 to August 10, 1931, the General Greene made a northern oceanographic cruise in the waters between Newfoundland and Labrador and southern Greenland. One hundred and twenty-two stations were occupied and about 1,700 well-located echosoundings were obtained in these poorly sounded waters. A chart (see pp. 254 and 255) showing the track of the ship and various other features of the northern cruise is attached to this paper.

The oceanographic results of the early season work will be published in the United States Coast Guard's 1931 ice-patrol Bulletin. The oceanographic data obtained during the two late season cruises are now being worked up and most of the results will be published soon in United States Coast Guard Bulletin 19, Part II, along with the main oceanographic results of the Marion Expedition of 1928.

The year 1932 promises to be one of more normal ice-conditions than 1931. The General Greene left the United States on March 4, 1932, on an ice-observation cruise. She carried new water-bottles, new thermometers, and a new thermograph. In addition, all the 1931 oceanographic apparatus was thoroughly overhauled and taken along.

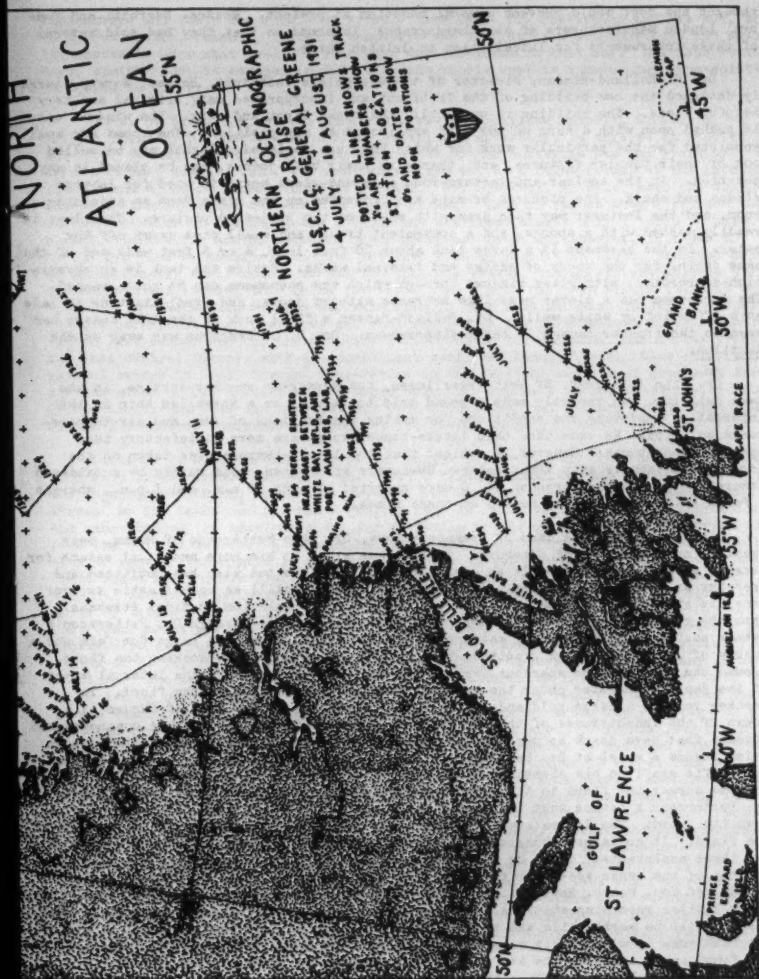
On April 1, 1932, the United States Coast Guard Cutter Tampa left Boston, Massachusetts, to inaugurate the regular ice-patrol service. On about April 15 the Pontchartrain will depart to relieve the Tampa. It is hoped that the General Greene, usually employed at oceanographic work just north of the larger ice-patrol vessel on duty by the southernmost ice-limits, will be able to construct dynamic-current maps that will be of value for predicting probable ice-drifts for the benefit of the ice-patrol service.

U. S. Coast Guard,
Washington, D. C.

A RECENT TOUR OF SOME OCEANOGRAPHIC CENTERS OF NORTHWEST EUROPE

Charles F. Brooks

What I saw on my brief visits to oceanographic institutions in England, Norway, Denmark, Germany, and France last August and September indicated a large and growing interest in oceanography. The Laboratory in Plymouth, England, had recently been enlarged to nearly double its former size and further construction was in progress. An aquarium for public exhibition (with charge for admission) is connected with the Laboratory. For stirring the experimental tanks slowly a clever syphon-device is employed. Director Allen was away, but Mr. H. W. Harvey, M.A., showed me through the Institution, including its fine new quarters for library and experimental laboratories. Mr. Harvey is working on a new edition of his book *Physics and Chemistry of sea-water*, and is tabulating the surface-salinities of the eastern North Atlantic by latitudes (ordinates) and by months (abscissae). Though interesting work is in progress under the direction of Mr. J. R. Lumby of the Fisheries Laboratory, Lowestoft, I did not have an opportunity to visit that station. Commander Hennessey, in charge of the Marine Division of the Meteorological Office, Kingsway, London, in the absence of Captain Brooke-Smith, said that his Division was not at present mapping sea-temperatures owing to insufficient staff. The data are available, however, on Hollerith punch cards. Commander Hennessey favored intake- over bucket-temperatures, and wanted to know how soon intake temperatures would become standard. He thought international action to secure uniformity would be desirable. He also favored the use of recording-thermometers, but



thought the cost would prevent general adoption at present. Messrs. Negretti and Zambra, London manufacturers of sea-thermographs, informed me that they had sold several of these instruments for installation on British ships.

Dr. B. Helland-Hansen, Director of the Geofysiske Institutt, Bergen, Norway, largely designed the new building of the Institutt and incorporated many original and very helpful ideas. The building is on a hill, the rooms light and airy. The windows can be pushed open with a turn of the hand and looked in any position. The rooms are well appointed for the particular work for which they are designed. Lights may be pulled out of their tubular fixtures, and, thanks to their ball-joints, can be placed in any position. In the seminar and lecture-room a ground-glass board is used for lantern slides and chalk. The pictures or maps are projected on the glass from an adjoining room, and the lecturer may then draw with chalk on the projected picture. The glass is readily washed with a sponge, and a convenient trough and small pipe carry off the water. In the basement is a large tank about 20 feet long, 4 or 5 feet wide and of the same depth, for the study of eddies and internal waves. Beside the tank is an observation-depression, with glass windows through which the phenomena can be photographed. The dark-room has a clever mass-like entrance without doors, and (red) lighting is made more effective by white walls. Dr. Helland-Hansen's field work of the 1931 season had been on the Armauer Hansen in the Mediterranean. Dr. H. U. Sverdrup was away on the Nautilus.

Dr. Finn Spinnangr, of Wettervarslingen, the Norwegian weather-service, in the same building, had recently made a round trip to America on a Norwegian ship in the interest of improving the conditions for making observations of sea- and air-temperatures on ships. He concluded that intake-temperatures are more satisfactory than bucket-temperatures. However, I noticed that the intake-temperatures taken on the Norwegian passenger ship Venus between Newcastle and Bergen could hardly be considered accurate. Sea-temperatures of 14°C were reported at both 10 a.m. and 1 p.m., whereas I found 13.2 and 13.8°C by bucket at these times.

In Sweden lives the dean of oceanographers, Dr. Otto Pettersson of Holma, near Lysekil, not far north of Göteborg. Here he has lived on his huge ancestral estate for decades and has not only built an oceanographic institute but also has outfitted and operates an oceanographic ship. At the age of 83 he is still as enthusiastic as ever over his studies of internal waves in the sea and their relation to tidal stresses. From the railroad station at Caseberg one drives a few miles through Dr. Pettersson's estate past cultivated fields, pastures, woodland (there is also a large fox farm and a quarry of ornamental black granite), to his large stone house overlooking the fiord. Around the walls of the spacious living-room are painted in colors the internal waves of the dense salt-water under the brackish water of the surface of the fiord. In another room is a large gold and silver vessel presented by the King of Sweden as a token of the indebtedness of the Swedish nation to Dr. Pettersson for his oceanographic studies that have meant so much to the national fisheries. In the arched dining-room below stands a model of Dr. Pettersson's ship Stavanger presented him by its crew and scientific staff on his eightieth birthday. After a sumptuous dinner a gasoline launch took us across the fiord to the oceanographic laboratory on an island. So extensive is Dr. Pettersson's estate that its limits could not be seen in either direction up or down the fiord. The laboratory is a three-story building clinging to the steep wall of the fiord. It contains laboratories, library, bedrooms, kitchen, and dining-room for the three assistants. Close by is a small shed housing the recorder for the float on the top of the dense sea-water that fills the bottom of the fiord (pictured in Fig. 1, p. 160, of Mon. Weath. Rev., v. 45, 1917). At several points down the fiord there are other similar recording-stations. Dr. Pettersson can advise fishermen accurately when fishing will be worth while and to what depth they should drop their hooks. In winter the fish come in with a thin warm layer of 5° to 6°C under the ice. Dr. Pettersson has found inner tides in the sea so important that he believes similar observations should be made elsewhere. When there is a strong fluctuation of tidal force the dense ocean-water flows far up the fiord along the bottom; but when there are but weak fluctuations the ocean-water does not come far. There is a fortnightly pulsation in the depth of the saline water. Dr. Pettersson believes he has a set of natural conditions that could not be excelled if made to order for his study. He hopes to get the Government to take over his work so it will go on. For extensive studies of sea-temperature and salinity Dr. Pettersson has brought about the installation of thermometers and density-indicators on the intake-pipes of a number of commercial vessels. These are

inexpensive and their use should be greatly extended. Dr. Pettersson and his son, Dr. V. I. Pettersson, recently issued a tentative set of monthly sea-temperature and salinity-charts to show what could be done with data obtained in this way. Dr. Hans Pettersson, another son, is engaged in Baltic oceanographic work in summer, but atom-splitting in Vienna in winter.

Dr. J. W. Sandstrom, of the Meteorologisk-Hydrografiska Anstalt, Stockholm, Sweden, formerly Dr. Pettersson's first scientific assistant, is engaged in studies of the Gulf Stream which he calls the warm water of the Norwegian Sea and vicinity. He said that last summer, 1931, the sea-temperature was 5° C below normal at the Lofoten Islands and 3° below normal south of Iceland. Mr. Bjørkdal, in Oslo, said the Gulf Stream in the Norwegian Sea was 3° C below normal. Late in August when I crossed the northern portion of the North Sea I found the sea-temperatures only 1° or 2° C below normal. In the far north, however, about Northeast Land, Spitzbergen, latitude 80° north, Dr. Hans W. Ahlmann, who just returned from an expedition there, reported such an exceptionally small amount of sea-ice that his vessel, the Quest, was able to circumnavigate the island, this being the first time a ship had been around it. The cool waters of the Norwegian Sea and westward seem to have been at least in part responsible for the persistent high pressures and cool weather in the northeastern North Atlantic region last summer and for the eastward deflection of the paths of lows across France and into central Europe, with the consequent cool, wet summer there. Some effects of general swings in Gulf Stream temperature on the seasonal weather of northwest Europe are described by Dr. Sandstrom in a paper that just appeared in the *Bjerknes-Testband* (J. W. Sandstrom, Über den Einfluss des Golf-Stromes auf das Wetter, Beitr. Physik der freien Atmosphäre, Bjerknes-Testband, v. 19, 23-26, Leipzig, 1932).

Capt. C. J. H. Speerscheider of the Danish Meteorological Institute, Copenhagen, is a very lively little man of 67 who takes a keen interest in, and is an authority on, the oceanography of the north polar waters. He deplored the use of the name "Gulf Stream" by Dr. Sandstrom for the Norwegian Sea; in fact, he saw little justification for the name even on the American side, for so little of the water in the Gulf Stream comes from the Gulf of Mexico. A responsibility of the Danish service is the annual publication of maps of ice-limits in the arctic. Capt. Speerscheider said the United States Coast Guard was good in sending him their information promptly. He has difficulty, however, in getting reports from Alaskan waters. The sea-temperatures of the North Atlantic north of latitude 50° is also considered one of the responsibilities of the Danish. Forty-year means are now available by small squares. Monthly maps of temperature are constructed and published annually. Observations of both temperature and salinity at depths of 5, 10, 15, 20, .. to 39 meters (the deepest water) are made at many light-ship stations. The temperatures are obtained with a thermometer in a hard-rubber case that is closed by copper tubing. It is left for an hour at the required depth, then hauled up and read. It does not change its reading in 15 minutes after being exposed to the air, and the thermometer does not break. The device is about 10 inches long and 3 inches in diameter. For surface-temperatures the thermometer is enclosed between two pieces of wood screwed together and varnished, making a holder 12 inches long and 2 inches square, with open front. The thermometers are of Jena glass. Each month the observer compares his thermometers in the same pail and reports the results of four tests. If the readings differ by more than 0.2 C the observer is cautioned. Furthermore, one man goes from ship to ship testing thermometers. Before the reported temperatures are used the office applies its own corrections for thermometer-error. The surface-temperature is obtained by hauling up a big bucket, supplied by the Meteorological Institute, and instructions are to stir the thermometer back and forth and read in one or two minutes, with thermometer in the water. On steamers with speeds of over 10 knots a smaller bucket must be used. Denmark feels responsible for mapping northern waters, for which it gets many data, especially from Denmark to Iceland, Denmark to Greenland, and Denmark to the United States.

Salinities are obtained by hydrometer floated in a vessel of water on gimbals. The samples of sea-water are obtained with a heavy brass bottle that is open on the way down, but is closed by messenger and then hauled up. The original device for obtaining a sample was a jug from which the cork was pulled at the desired depth. Once a month a sample is preserved for titration to check the hydrometers.

The daily weather-map of the northern hemisphere now being made for the International Meteorological Organization by the Deutsche Seewarte, in Hamburg, includes sea-surface

temperatures. While these are mapped for their meteorological interest, they also furnish a basis for synoptic isotherms of sea-surface temperature by days or by weeks, but, unfortunately, the observations are of questionable accuracy. The reports placed on these maps are official values received by mail from the various countries.

Dr. Gerhard Schott, of the Deutsche Seewarte, is now working on a geography of the Pacific Ocean corresponding to his monumental work on the Atlantic. The errors of observing sea-temperatures by the bucket-method noted by me on the German ship Columbus (see article following this one) were discussed with Dr. Schott and Dr. Kuhlbrodt. Both agreed that an effort should be made to improve the accuracy. Dr. Schott showed the data I had collected to a class of teachers of meteorology in seamanship schools, then at the Seewarte, and Dr. Kuhlbrodt spoke of the need for a new book of instructions, the last being that by Neumayer in 1893, of which no copies are now available. There was nobody to make visits from ship to ship. Dr. Kuhlbrodt said that two million observations had been received in the past few years but that nothing was being done with them, nor had been for nearly 20 years. Perhaps this is just as well, however, for the data, especially on fast ships, are not so good as in sailing-ship days. Therefore, for investigations in marine meteorology, Dr. Kuhlbrodt said not to use modern observations.

In the absence of Dr. Defant, Director, Dr. G. Wüst showed me around the Institut und Museum für Meereskunde in Berlin. A roomful of workers were busy on the data collected by the Meteor Expedition, and Dr. Wüst said it would take two years more to finish. The instruments and apparatus used on the Meteor are on exhibit in the spacious museum and many of the results are also shown. Not only are the oceanographic instruments shown but also the method of use is indicated in many instances. The stages in the construction of deep-sea thermometers are illustrated by samples. These thermometers are accurate to 0.003 C, and can be read to thousandths though graduated to twentieths. There are three different scales, for upper, middle, and deep-sea use. Each sounding is made with two thermometers one of which is unprotected. A difference, due to the pressure to which the unprotected thermometer was subjected, indicates the depth. The Institute has a catalog of all deep-sea observations and would welcome American cooperation to keep it complete. One surprising fact, which, however, will soon be altered, is that the Weddel Sea is better known than the Gulf Stream. There are seminar and work-rooms in the Institute for the 50 to 100 students studying there.

In Paris, Dr. Alfonse Berget, Director of the Oceanographic Institute founded there by the late Prince Albert of Monaco, showed several members of the International Geographical Congress through the well-equipped building. A considerable collection of marine biological specimens is being studied. There is a lecture-hall beautifully decorated with large paintings of work in progress on the oceanographic vessel of the Prince. M. Berget told us of the considerable support to oceanographic work gained from the admission charge to the museum in Monaco. The equivalent of about \$50,000 a year is collected.

En route across the Atlantic on the express liners Columbus and Bremen I made a study of the accuracy of the hourly bucket-observations of sea-temperature, which are presented as a brief addendum in the following paper.

Harvard University,
Cambridge, Massachusetts

SEA-TEMPERATURES BY BUCKET ON EXPRESS LINERS

Charles F. Brooks

En route across the Atlantic on the large North German Lloyd express liners Columbus and Bremen, in August and October, 1931, I observed the use of canvas-buckets in making observations of sea-surface temperature, and checked the accuracy of the results. The Columbus is 775 feet long, has 32,354 gross registered tonnage, and travels at a speed of about 21 knots. The Bremen is 938 feet long, of 51,656 tonnage, and of 28 knots speed. On ships of such size and speed it is obvious that samples from the surface can be obtained regularly only near the stern. To do this is contrary, however,

to the usual instructions to obtain samples forward of the outtakes, but stern hauls have the advantage of less exposure to wind than those from a position forward.

The regular program on both ships included hourly or half-hourly (near Grand Banks) sampling of the surface-water. On the *Columbus* the water was dipped from the wake with a canvas-bucket of 5-liters capacity and hauled 8 or 9 meters to the lowest open deck at the stern. On the *Bremen* the water was dipped from the side of the ship well aft with a canvas-bucket of 3-liters capacity and hauled about 15 meters to the lateral overhang at the stern end of the sun-deck. Either job was considered arduous, for on several occasions the quartermasters reported the previous temperature rather than make a new observation.

On the *Columbus*, en route from New York to Plymouth, August 16 to 21, 1931, I made frequent observations of sea-temperature, 13 of which were within 10 or 15 minutes of the time the quartermaster made his observation. I used my own 2-liter iron bucket for six of these and the ship's canvas-bucket for the other seven, when the wind was so strong that my bucket blew out horizontally. After allowing for the +0.6 C error I found in the ship's thermometer, my temperatures, obtained quickly, averaged 0.3 C higher than the quartermaster's, which were made with less dispatch. For example, one quartermaster threw the bucket, obtained a catch promptly, hauled it up, tied the bucket to the taffrail, inserted the thermometer, coiled the rope, withdrew the thermometer from the water and read it. The reading was made about 1-1/2 minutes after the sample was caught. Another quartermaster, in a hurry, dipped half a bucketful, put the thermometer in for 35 seconds, pulled it out and read it in 3 or 4 seconds.

The difference between my observation and the quartermaster's was found to be roughly proportional to the depression of the wet-bulb (air) temperature below the sea-temperature at the time. In four cases with wet-bulb depressions from 0.4 to 3.4 C (mean 2.0) my temperatures and the quartermasters' in each case agreed within 0.1 C and averaged the same temperature. In four cases with depressions of 3.8 to 6.9 C (mean 5.1), however, my observations ranged from 0.1 to 0.6 C higher and averaged 0.4 C above the quartermasters'. I did not have wet-bulb temperatures for the other five comparisons. The average difference of the 13, 0.3 C, was only half as great as the 0.6 C average cooling I found in ships' canvas-bucket observations in previous studies (Charles F. Brooks, *Observing water-surface temperatures at sea*, Mon. Weath. Rev., v. 54, 241-254, 1926, and *Reliability of different methods of taking sea-surface temperatures*, J. Wash. Acad. Sci., v. 18, 525-545, 1928). I attribute the greater accuracy to the greater ease of making a catch in the turbulent wake, the lesser haul, and the shorter exposure to evaporational cooling. Twice in the 13 comparisons the record of temperature in the log differed from the observation as made by the quartermaster, once by 0.9 C and the other time by 0.1 C. The quartermaster does not write his observation, but tries to remember it from the time he observes till 5 to 15 minutes later when he is phoned from the bridge by another quartermaster for his report.

Returning on the *Bremen*, October 1 to 7, from Bremerhaven to New York, I made a special effort to check the accuracy of the regular bucket-observations. The equipment and method on this ship are as follows. Like that on the *Columbus*, a mercury thermometer is used, with spherical bulb and an open scale protected by an outer glass tube. It is mounted in an open-front wooden holder, with an ample hole to expose the bulb. The thermometer can very readily be read to 0.1 C intervals, and it will come to the water-temperature in only 10 seconds. This thermometer, at 14.3 C and 16.1 C, was found to be correct to within less than 0.1 C.

The bucket on the *Bremen* lacks only a sufficient capacity to make it all that a canvas-bucket for sea-temperatures should be. It is appreciably smaller than that on the *Columbus*, for although the rope ring at the top has the same diameter (15 cm) and the depth (about 27 cm) is the same, the bottom, instead of being rounded as on the *Columbus*, is sewed together like a pocket. The reduced capacity, three instead of five liters, is compensated for somewhat, however, by the greater ease with which the sharp bucket enters the water. Also, a coat of paint on the smaller bucket helps shed water from the outside and thereby reduces evaporational cooling on the small sample. The bucket is held by ropes from opposite sides of the rim which come together about 20 cm above and join a ratline some 20 meters long. An iron weight of about one kg is occasionally attached to one side of the handle of the bucket. Sometimes, however, the

remnant of water still in the bucket from the previous observation would be used as the sinker!

A sample of water is obtained by throwing bucket and coiled rope downward from the overhanging projection on the lee-side of the stern end of the sun-deck. The bucket strikes the water one or two meters from the side of the ship but not far enough out to be beyond the three-meter belt of turbulent ship-side water which includes the hot outtake from the condenser. The bucket is allowed to drift for a second or two, is pulled up a little and allowed to drop into the water again, and then is hauled up rapidly to the deck. It takes from 10 seconds to a minute to make a catch and then 20 seconds to haul the bucket up. The thermometer is inserted and the bucket tied to the rail. When the rope has been coiled (half a minute) some quartermasters read the temperature but others leave the thermometer in the water 1-1/2 to 4 minutes. The reading may be made to the nearest 0.1 C but is reported usually only to half or whole degrees.

In a period of minutes there can readily be an appreciable change of temperature in a sample of two or three liters exposed to the wind in a wet container. Usually the wet-bulb temperature is below the sea-temperature, so a fall takes place. Ten observations of the change in the temperature of the canvas-bucket of water hung on the exposed rail of the ship showed a cooling in eight instances and a warming in two. In either cloudy or sunny weather the cooling of a bucket nearly full was found to average 0.5 C in 3 or 4 minutes with a wet-bulb temperature 3° C below the bucket-temperature. After this interval the painted outside of the bucket would become dry and the rate of cooling would be reduced to a slow approach to the air-temperature. For example, one set of observations showed that in the first two minutes the bucket of water cooled 0.5 C with the wet-bulb 5° C below the bucket-temperature; in the next 13, however, the temperature fell but 0.2 more, reaching the air-temperature. Once, with wet-bulb 0.7 C above the bucket-temperature, the bucket warmed 0.1 in four minutes. Another time, the bucket, starting at the wet-bulb temperature, rose 1.0 C in 16 minutes, nearly to the air-temperature. So strong is the wind in the exposed position of the bucket that sunshine was found to have no appreciable effect on the temperature of the bucket.

Of the numerous observations I made with a two-liter iron (tin) bucket from the stern of the *Bremen*, 38 were at practically the same time as the quartermasters hauls at the side of the ship. Some were simultaneous; others, to the best of my knowledge, were not more than 8 minutes after the quartermasters hauls. Observations of wet-bulb temperatures were made immediately before or after each haul. The quartermasters' observations, as on the *Columbus*, were not recorded by the observer but borne in mind and a few minutes later given to a quartermaster on the bridge when called for by phone. In half the cases (19) I was present when the quartermaster made his haul or soon after and obtained from him the temperature observed. In seven of the 19 instances the value written in the log differed from what the quartermaster told me. At times other than when I made my check-observations close enough to the quartermasters' observations I obtained his temperatures direct from him. Out of 49 such occasions 21 differed from the subsequent entries in the log. The differences were from 0.2 to 5.0 C, and averaged 1.2 C. All these differences were not errors in transmission, for it is evident that some uncooperative quartermasters would say anything to satisfy my question as to temperature, since the recorded values often are more consistent than the quartermasters' reports to me. I must add, also, that it is not impossible that the temperatures as stated, always in German, may occasionally have been mistaken by me. Both sets of values are shown in Table 1.

Table 1 shows a consistent relation of the sea-temperature obtained by the quartermasters on the *Bremen* to the depression of the wet-bulb temperature below the sea-temperature. In cases where the depression is slight the small sample hauled up from the water at the side of the ship near the stern averages 0.3 C and at times is more than 1° C higher than the sea-temperature found by quick hauls from the great masses of water upwelling from the propellers. This excess appears to be due to the mixture of hot outtake water with the mass of sea-water through which the ship passes. The evaporational cooling that attends a depression of the wet-bulb thermometer about 1° C below the sea-temperature, however, is sufficient to wipe out the excess of temperature ascribed to the outtake, while the evaporation with a 2° C depression, the average found at the times of the 38 comparisons I made while crossing the North At-

Table 1--Errors of sea-temperature observations by canvas-bucket thrown from sun-deck to water at side of ship aft: quick observations by iron bucket in wake of ship within 8 minutes of canvas-bucket observation time used as the standard

a--Hauls of canvas-bucket seen by C. F. Brooks

No. of cases	Wet-bulb minus sea-temp.		Sea-temp. as read by quartermasters on ship-side minus CFB's temp. in wake	
	Extremes	Mean	Extremes	Mean
	°C	°C	°C	°C
2	1.4, 0.8	1.1	1.6, 0.3	0.9
7	0.3, -0.5	-0.2	1.4, -0.3	0.1
3	-0.6, -1.3	-1.0	-0.1, -0.4	-0.3
2	-1.7, -3.0	-2.4	0.1, -1.1	-0.5
1	-8.8	-8.8	-1.4	-1.4
15	1.4, -8.8	-1.0	1.6, -1.4	-0.06

b--Hauls of canvas-bucket both seen and not seen by C. F. Brooks

No. of cases	Wet-bulb minus sea temp.		Sea-temps. on ship-side minus CFB's temps. in wake			
			As told CFB by QM or in log		As recorded in log	
	Extremes	Mean	Extremes	Mean	Extremes	Mean
	°C	°C	°C	°C	°C	°C
4	1.4, 0.8	1.0	1.6, 0.3	0.9	1.6, 0.7	1.1
13	0.4, -0.5	-0.1	1.3, -0.4	0.3	1.3, -0.4	0.2
5	-0.6, -1.6	-0.9	0.3, -0.4	-0.2	0.3, -0.4	-0.2
7	-1.7, -3.0	-2.4	0.1, -1.8	-0.7	-0.1, -2.1	-1.0
5	-3.2, -5.6	-4.4	-0.1, -2.2	-1.0	-0.1, -2.2	-1.3
4	-6.7, -8.8	-7.9	-0.8, -1.5	-1.2	-0.8, -1.5	-1.2
38	1.4, -8.8	-2.0	1.6, -2.2	-0.2	1.6, -2.2	-0.3

lantic from the English Channel to New York early in October, 1931, produces a further cooling of 0.2 or 0.3 C. The total evaporational cooling with a 2 C depression of the wet-bulb temperature thus amounted to 0.5 or 0.6 C, exactly the same as that which I found on a February and March cruise from New York to the north coast of South America and return in 1924 (Mon. Weath. Rev., v. 54, 241-254, 1926). It is interesting to note that the net error on the Bremen from the excess heat and greater cooling was the same as that on the Columbus on which the method did not involve outtake water and, on account of reduced exposure and larger samples, included but half the evaporational cooling in the Bremen observations.

Where is the best place for taking bucket-samples? Obviously, the best is not near the bow, where it is difficult both to make a catch and to get the temperature of the sample before it is cooled appreciably by the wind. Nor is it on the side of the ship back of the outtakes, where a mixture carrying an unknown, though usually small, proportion of ship water is sampled. Though the wake is not free of outtake-water the variability of two to five successive dips minute after minute in groups averaged so small, 0.1 C, that the warming by outtake-water is evidently inconsequential. The maximum change from one dip to the next was 0.5 C and only 9 of the 87 times did it exceed 0.2 C. Half of the variability of successive hauls seems due to differences in the amount of cooling of the samples by evaporation, for each catch is not made equally fast, nor is the quantity of water caught the same. Furthermore, there are local differences in sea-temperature, and perhaps also in the temperatures of the waters thrust to the surface by the propellers from different depths. When all these sources of variability together do not average more than 0.1 C, no one can be large enough to be of consequence.

To determine the evaporational factor the variabilities of the 87 immediately successive pairs of hauls made on the Columbus and on the Bremen were tabulated against the depressions of the wet-bulb temperature below the sea-temperature at the time. The results are shown in Table 2.

Table 2--Depressions of wet-bulb temperature below sea-temperature with different degrees of variability of bucket-sample temperature taken from the wake of the ship

Variability	<u>Columbus</u>		<u>Bremen</u>		Both ships	
	Mean wet-bulb depr.	No. of cases	Mean wet-bulb depr.	No. of cases	Mean wet-bulb depr.	No. of cases
"F	"F		"F		"F	
0.0	4.6	10	4.6	9	4.6	19
0.1	8.0	13	8.0	16	6.3	29
0.2	6.8	6	7.0	4	6.9	10
0.3	7.9	3	8.1	4	8.0	7
0.4	4.3	10	12.4	3	6.2	13
0.5	2.3	3	7.1	2	4.2	5
0.6	...	0	13.4	1	13.4	1
0.7	...	0	...	0	...	0
0.8	7.8	1	...	0	7.8	1
0.9	...	0	4.3	1	4.3	1
1.0	7.8	1	...	0	7.8	1
Means 0.2	6.0	47	6.3	40	6.1	87

There is a fairly consistent increase of wet-bulb depression with variability from 0.0 to 0.3 or 0.4 F amounting to about 1° for each 0.1, but beyond this there is no apparent relation; however, for the most part, the number of cases is insufficient for good means. Since 0° variability occurred with 4.6 F mean wet-bulb depression, a value lower than the 6.1 F mean for all the comparisons, and since the mean for 0.1 variability, 6.3 F, is close to the general mean, it seems likely that the variable effect of evaporation was responsible for half of the 0.2 F mean variability of the 87 pairs of hauls.

The diverse evaporational effect arises, as already remarked, from the unequal quickness and quantity of the catches. Sometimes on the Columbus, which has an under-out stern, my iron (tin) bucket would be blown out horizontally by the wind and only by means of the heavier canvas-bucket could a haul be obtained. The nearly vertical stern of the Bremen provided sufficient shelter, however, to permit observations with the light iron bucket and clothes-line at all times. The stern is, obviously, not altogether sheltered from the wind, but so quickly can a catch be made and the temperature obtained (altogether not more than 30 seconds) that evaporational cooling need not exceed 0.1 C on the average nor an extreme of 0.3 C. In the slower practice of the quartermasters on the Columbus the average cooling compared with my rapid determinations was 0.3 C and the extreme, 0.5 C. Even these values, while larger than they need be, are small relative to the 0° to 6° C (average 1.0 C) changes in sea-temperature encountered from hour to hour as the express liner speeds through the water.

The Bremen was equipped with an intake-thermometer on the bridge which read from 0.2 C below to 1.5 C above (mean 1.0 C above) the bucket-temperatures I obtained within half an hour of the time of the intake-reading. The water was said to enter the ship at a depth of three or four meters, whence it was pumped to the bridge through at least 30 meters of pipe.

On the fast ship Venus, Newcastle to Bergen, sea-temperatures are not observed with a bucket, but the refrigerator intake-temperature is taken from the 3-hourly meteorological records. I was told by the radio operator that the pump was turned on an hour before the observation was to be made. The temperatures reported were 0.6 and 0.2 C above those I obtained by bucket within 15 minutes of the hour for which the report was made.

Intake versus bucket--While intake-temperatures appear to yield the best opportunity for an accurate continuous record of the temperature of the surface-layer of the sea, it by no means follows that eye-readings of intake-temperatures will yield data more accurate than bucket-observations. Continuous intake and, if a thermograph is too expensive, a careful reading of an accurate thermometer inserted in the stream not too far from the intake seem necessary for satisfactory observation of sea-temperature by the intake-method. Though fairly accurate results can usually be obtained from samples dipped from the propeller wash of the ship, the considerable variation in the depth from which the water has come, the occasional intermixture of small quantities of hot outtake-water, as well as the practically unavoidable and highly variable errors introduced by the cooling or warming of the water-sample by the air, make deviations from true sea-temperature which no amount of care can prevent. Therefore, it might seem obvious that consistently accurate temperatures of the surface-layer of the sea can be obtained on a modern ship only at the intake and that the intake-temperature should be recognized as the standard.

Bucket versus intake--Nevertheless, if there is no thermograph, the considerable parallax error of an intake-reading (discussed fully in my 1926 paper) may be more difficult to eliminate than most of the evaporational cooling of the canvas-bucket measurement. Furthermore, it would be expensive to supply numerous ships with intake-thermometers that readily permit a reading to 0.1 C. The improvement of the bucket-method, however, would cost little or nothing for each ship. Therefore, I think it worth while to present a set of specifications for observations by bucket which will be practicable on any vessel, from dory to express liner. I feel confident that if these specifications are substituted for the present unsatisfactory ones our thousands of bucket-observations coming in each month may become useful in refined investigations of the distribution of sea-temperature.

Equipment and method for bucket-sampling of sea-temperature--Observations of sea "surface" temperature can be made by the bucket-method with a degree of accuracy fully as satisfactory as that of the determination of the position of the ship. And the care necessary does not presume too much on the interest or energy of the quartermasters. Supervision, however, as, in fact, in the case of any other duty to be performed more than perfunctorily, is required. Sea-temperatures in all weathers should be obtainable within 0.5 C and ordinarily should be within 0.1 C if the following specifications are heeded.

Equipment--(A) Thermometer (1) accurate to within 0.1 C through a range from -2.0 to 35 C; (2) open clear scale, readable to 0.1 C; (3) quick to respond, permitting determination of temperature in not more than 20 seconds; and (4) protecting case of soft wood or of metal sheeting with bumpers. (B) Bucket (5) made of canvas, double thickness; (6) capacity of 4 to 6 liters; (7) diameter at top 15 to 20 cm; (8) bottom sharp or rounded, to cleave water when dropped; (9) painted; and (10) weight attached to handle.

Program--(C) Frequency of observation (11) at least one every 60 miles; and (12) as often as practicable where sharp contrasts of temperature. (D) Regularity of observation (13) each regular observation should be within 5 minutes of times adopted as standard; and (14) special observations may be added at any time.

Method--(E) Place for sampling (15) stern; (16) lowest open deck; (17) leeward side; and (18) as near center-line of wake as practicable. (F) Making the catch (19) dip in the upwell from propeller; (20) accept no less than 3 liters; (21) complete catch in less than 20 seconds, if not dump bucket and try again; and (22) haul up quickly--10 seconds enough. (G) Obtaining the temperature (23) insert thermometer as soon as bucket comes over the rail; (24) while holding bucket in one hand move thermometer slowly back and forth with other--at night carry bucket to light while doing this; (25) read thermometer in 15 to 20 seconds without withdrawing bulb from water; (26) read to nearest 0.1 C; and (27) write in notebook the temperature, hour, minute, and date. (H) Preparation for next observation (28) empty bucket and hang it up to dry.

Harvard University,
Cambridge, Massachusetts

BLANK PAGE

CONTENTS

	PAGE
SECTION OF VOLCANOLOGY.	265
Central American volcanoes in 1932. E. G. Zies.	267
The volatility of silica with steam. George W. Morey.	269
Volcanologic developments in 1931-32. T. A. Jaggar.	271

CENTRAL AMERICAN VOLCANOES IN 1932

E. G. Zies

A preliminary survey of the volcanological activity of the Republics of Guatemala, El Salvador, and Nicaragua was made during the first three months of 1932. The object of this survey was to learn what types of activity prevailed and to determine if this area is of sufficient interest to warrant more intensive petrological, geological, and chemical studies. The conclusion was reached that such studies were distinctly worth while. Considerable work of a descriptive nature has already been done in this region by Dollfus and Montserrat and, in later years, by Karl Sapper.

Evidence of extensive activity in the past is shown by the huge deposits of tuff in the three countries visited by the writer. There are areas in western Guatemala where the country is so completely blanketed by such material that one almost looks in vain for a true lava-flow. This is especially the case in the Lake Atitlán district of Guatemala, in the Lake Coatepeque and Lake Illopango districts of Salvador, and in the crater-lakes district of Northern Nicaragua. Practically all of the nine active volcanic areas visited in 1932 were covered in part, at least, by extensive deposits of tuff. In many places this tuff often seems to be quite fresh; in other places it is obviously altered.

Other evidences of ancient explosive activity can be seen in the stratified beds of ash particularly such as appear in Salvador. On the volcano of Santa Ana an interesting sequence was found at the coffee plantation of Malacara. A bed of stratified pumiceous material and ash was overlain by a deposit of black soil two feet thick which in turn was capped by a lava-flow. Such a sequence is fairly common in this country. The writer was also impressed with the general presence of elastic material and the paucity of recent lava-flows on the slopes of the volcanoes in Guatemala. In Salvador, on the other hand, recent (within the last hundred years) lava-flows are common, especially so at the volcanoes, Isalco, San Salvador, and San Miguel. Tuffs, ash, and elastic material are also to be found in abundance in this republic.

The limited time available permitted but a brief study of the chemical activity found in the craters.

Guatemala

The gases emitted by Santiago, the recently formed volcanic dome of Santa Maria, were shown to consist of steam and sulfur dioxide; practically no hydrogen sulfide was found. It is quite likely that all sulfur products are oxidized by air aspirated into the loosely consolidated mass of lava-blocks by the escaping gases. The temperature of the gases ranges from 93° to over 400°. The activity since 1929 is confined to the emission of great volumes of steam and sulfur dioxide and to the expulsion of hot rocks and small dust-clouds from the west flank and near the base of the dome. Santa Maria has been almost continuously active since 1917.

Fuego (about 12,300 feet high) has been dormant for a period of 50 years but after a series of sharp tremors it quite suddenly burst into eruption on January 21, 1932. No fresh lava was extruded. Huge volumes of comminuted material were thrown into the air by a series of violent explosions which removed about 400 feet of the top of the volcano and eviscerated the cone to the extent of about 1,500 feet. In addition, a great mass of red-hot fragmental material was ejected in such a manner that it flowed down the steep eastern slope of Fuego and in part was deposited in the Barranca Honda where it accumulated to a maximum depth of 100 feet. The stream of hot, rapidly-flowing material divided near the lip of the newly formed crater. One part flowed down the Barranca Honda whereas the other portion scoured out a new ravine in its rapid progress down the slope. The comminuted material came down so hot and with such speed that huge blocks of stone were, according to observers, literally floated down. The new crater was visited about three weeks after the eruption. Immense volumes of steam and acid gases were being emitted from hundreds of steam-vents located in the inaccessible bottom and on the very steep slopes of the crater. At the eastern end of the main crater there is a still deeper pit from which the huge distinct steam-cloud that can be seen for miles around is emitted. The crater has an elliptical outline and measures approximately 2,500 feet across the long axis and 2,000 feet across the short

axis. That hydrochloric acid is one of the constituents of the steam-cloud is easily shown by the presence of ferric chloride in the incrustations, by analysis of the aqueous extract of the so-called ash that fell immediately after the eruption and by the very sour taste of the emanations.

The present activity of the Pacaya is confined to the low-temperature fumaroles (below 70°) in the crater and on the slopes of the main cone. The top of this cone has only very sparse vegetation whereas in the vicinity of the fumaroles the condensation of the steam permitted the establishment of a lush growth of mosses and other low forms of vegetation. There is, however, much greater activity in a series of craters in another part of the great Pacaya massif. These craters are near the village of Calderas. The temperature of the steam is close to the boiling point of water at this altitude (about 95°) and contains hydrogen sulfide. Sulfate incrustations are abundant. The region is rarely visited but according to the tradition of the natives this area has been active for over a hundred years.

Acatenango (13,000 feet), which adjoins Fuego and forms with it what looks like a great massif with twin peaks, was apparently not influenced by the eruption of this volcano. Very slight steam-activity was noted near the new explosion crater that was formed on Acatenango in 1924. Incrustations were found but it was obvious that these were only vestiges of a former much greater activity. This lack of outward manifestations of a volcano that is in a way a twin of Fuego would indicate that the paths of egress developed in 1924 were probably completely sealed. The crater that was formed at this time reveals the core of Acatenango Peak. A detailed petrological and morphological study should be made of this volcano; such a study is likely to furnish interesting details as to structure, lava-sequences, and rock alterations.

The activity at Tecuamburro is confined to carbon dioxide emanations in the rock mass shaken down during a recent earthquake and to the emanations issuing from the shore and bottom of the acid lake of Ixpaco.

El Salvador

From the chemical point of view the most interesting areas for future study in Salvador are the extensive fumarole areas at Ahuachapán, the acid crater-lake of Santa Ana, the water of Lake Coatepeque (probably a crater-lake), and the hydrochloric acid fumaroles in the very active crater of San Miguel. Santa Ana and San Miguel with their series of more or less concentric cones and extensive series of lava-flows should furnish valuable data for morphological and petrological studies.

Izalco located on the flank of Santa Ana is at present the most active volcano in Central America. In 1930 two lava-flows were extruded, one from the slope and the other from the crater itself. The activity is now of the explosive type, often accompanied by flames. In the course of eight hours eight eruptions of stone and ten eruptions of dust and steam were noted. It was observed that the stone eruptions were accompanied by only light dust- and steam-clouds; the heavy cauliflower clouds of dust and steam were accompanied by relatively few rocks. The time interval between eruptions varied from five minutes to an hour. The activity was so intense that the writer was able to get only within 800 feet of the crater-rim. It was also noted that many of the rocks were hot but many were cold. It was observed that the ejected rocks broke off in their travel upward the cold rocks of the crater-rim and in falling dislodged rocks on the upper part of the slope. The slopes were literally sprayed with rocks during these eruptions.

Attention should also be directed to the desirability of making petrological studies of the series of lava-flows that have issued in the last hundred years from Izalco, San Salvador, and San Miguel, also to the tuff-deposits that border on the lakes of Coatepeque and Illopango and to the probable origin of these lakes.

The volcanic activity of Nicaragua was viewed from the air. The aeroplane furnishes one with an admirable method for making a very rapid survey of a volcanic area that is so rich in detail as Central America. The lava stands out almost startlingly sharp. This method of navigation also allows one to study the orientation of the volcanoes and to quickly determine the position of the shoulders that are such a common but little understood feature of Central American volcanoes. Finally, with a little

nerve and, most important of all, a good pilot, one can approach close enough to some of the active volcanoes that, given a background of experience, one can obtain with the aid of the eye and the nose considerable preliminary information as to the chemical activity of the vent under investigation.

In this manner it was found that Momotombo is now active, that it is giving off hydrochloric acid, that many incrustations contain sulfur, that chlorides and sulfates abound, and that numerous lava-flows have issued from the crater and the flanks. Likewise the great extent of the tuff-deposits in this area was noted. Finally, the crater-lakes with their walls of pumice were likewise observed.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

THE VOLATILITY OF SILICA WITH STEAM

George W. Morey

In 1930, Van Nieuwenburg and Blumendal (C. J. Van Nieuwenburg and H. B. Blumendal, *Rec. trav. chim. Pays-Bas*, v. 49, 857, 1930) published results of experiments which indicated a marked solubility of silica in a compressed aqueous vapor. In two later publications (C. J. Van Nieuwenburg and H. B. Blumendal, *Rec. trav. chim. Pays-Bas*, v. 50, 129 and 989, 1931) they give the results of further experiments, in which the transport of silica through the aqueous vapor is utilized to produce pneumatolytic syntheses of several minerals. The transport of silica through a highly compressed aqueous vapor is a phenomenon which is in harmony with certain geological speculations; for example, the presence of well-developed quartz crystals in lithophyses is commonly ascribed to such vapor-transport. Experimental evidence demonstrating the reality of such a solubility of silica in a compressed aqueous vapor-phase above the critical temperature of water would be of importance in geology, and would meet with a sympathetic reception. Nevertheless, the magnitude of the transport found by Van Nieuwenburg and Blumendal is surprisingly large, and is not in harmony with the work of the many others who have heated silica with water in bombs. For example, Table 1 is reproduced from the first paper cited, and shows a transport of as high as 0.3 gram of silica in 24 hours. With so marked a solubility of silica in the vapor-phase one would expect amorphous silica to crystallize completely to the stable phase, quartz, over night; but with pure amorphous silica the crystallization is slow, and the unstable forms, tridymite and especially cristobalite, are commonly formed.

Table 1--Twenty-four hours, 300 atmospheres, 395° C

	Weight lost mg	Weight recovered mg
Quartz	52.6	46.1
Tridymite	204.5	179.9
Cristobalite	118.0	108.1
Amorphous SiO ₂	295.3	280.1

Attempts to duplicate the results with silica have not been successful. The first experiments were made in a manner similar to that described by Van Nieuwenburg and Blumendal, in which the silica was contained in the lower of two crucibles, ZnO in the upper, and both supported above the bottom of the bomb. The amount of water which should be put into the bomb with such an arrangement is limited by the expansion of the water, which should not overflow the top of the lower crucible. It is evident that the greatest care must be taken to avoid this occurrence, since if water flows into the lower crucible it will surely carry some silica into the upper crucible by means other than transport of dissolved material through a vapor, and thus lead to erroneous conclusions. In the only case in which there was a noticeable amount of loss in weight of the crucible containing the silica, and gain in weight of the crucible containing the ZnO, the amount of water before heating was a little less than one-third the volume of the bomb, and the top of the bottom crucible was about one-half way to the top of the bomb. The change in this case was a decrease in weight of the silica

amounting to 0.0110 gram, and a gain in weight of the ZnO amounting to 0.0098 gram. In the later experiments a steel bomb was used the internal diameter of which was 16 mm; height of chamber, 48.2 mm; volume, 9.7 cc. From a silver hook were suspended two gold crucibles, each 16 mm deep, and semi-circular in cross-section with a diameter of 12 mm. Thus the two, suspended side by side, gave an assembly circular in cross-section. The tops of the crucibles were 7 mm below the top of the bomb. The volume of the gold in the crucibles was 0.2 cc, leaving a free volume in the bomb of 9.5 cc; and of the total volume 85 per cent, or 8.1 cc, is below the top of the crucibles. Since the critical volume of water is 3.086 cc per gram (the best values for the critical constants of water are $t_c = 374.11^\circ\text{C}$, $p_c = 218.55$ atmospheres, $v_c = 3.086$ cc per gram; see F. G. Keyes and L. B. Smith, *Mech. Eng.*, v. 53, 132, 1931), 3.08 cc would just fill the bomb with liquid at the critical temperature and overflow the crucible, and the amount of water used in all the experiments was 2.5 cc. This would give a pressure at the critical temperature of less than 176 atmospheres, and at 400° , less than 183 atmospheres.

Several experiments were made at various temperatures, using either quartz or amorphous silica. The amorphous silica had not been ignited, and contained 10.80 per cent water. The results are assembled in Table 2. Two experiments were made at 400° ,

Table 2--2.5 cc H_2O ; free volume 9.5 cc

Temperature °C	Time	Change in weight	
		SiO_2	ZnO
		gram	gram
400	24 hours	-0.0001	+0.0002
400	5 days	-0.0003	-0.0003
415	5 days	+0.0029	+0.0000
415	24 days	-0.0005	+0.0007
490	5 days	-0.0004	-0.0002

one for 24 hours, one for 5 days, but neither showed a change in weight which was significant. If the change in weight is caused by transport of SiO_2 through a vapor-phase, with condensation in the ZnO with formation of willemite, the amount of transport should be proportional to the time, but no difference was found. Two experiments at 415° for 5 days and for 24 days gave similar results. One experiment was made at 490° , and it also gave no evidence of appreciable transport. With the exception of one experiment at 415° , in which there was an increase in weight, probably caused by some accident, the SiO_2 lost weight in each experiment, and the possibility of some transport has not been excluded. But there can be no doubt that the large values found by Van Nieuwenburg and Blumendal have not been confirmed.

It was desired to duplicate the conditions of temperature and pressure under which Van Nieuwenburg and Blumendal worked, but some discrepancies in the conditions given by them make it not possible to accomplish this. For example, in their Table 1, reproduced above, the pressure is given as 300 atmospheres at 395°C . Such a pressure cannot be obtained unless more than the critical volume of water is placed in the bomb, when it will completely fill the crucible with liquid below the critical temperature. The possibility that the expansion of the liquid would cause the crucibles to be immersed in liquid, with opportunity for transport through the liquid instead of through the vapor, presumably has been considered; but the marked discrepancy between the results of Van Nieuwenburg and Blumendal, reproduced in Table 1, and the results summarized in Table 2 requires some such explanation. The experiments are being continued.

Geophysical Laboratory,
Carnegie Institution of Washington,
Washington, D. C.

VOLCANOLOGIC DEVELOPMENTS IN 1931-32

T. A. Jaggar

(Published by permission of the Director, United States Geological Survey)

The year 1931 was an interesting one in the production of a succession of eruptions, and earthquake-catastrophes in volcanic lands, while for the United States it was a year of expanded organization in the study of volcanoes, chiefly in Hawaii, under the Government. It was not a year of any colossal steam-blast eruptions, other than Aniakohak, which have come to my knowledge.

There was a succession of interesting volcano-developments in the Aleutian belt. The year brought to a focus the condition of unrest which had appeared in several volcanoes in 1929 and 1930. Akutan was smoking in 1928, probably Chignagak was fuming in March 1929, as were Mount Cleveland and a volcano west of it in the Islands of the Four Mountains. Shishaldin was reported flinging out fiery matter in May and June 1929, and Gareloi in the western islands erupted so violently in 1930 as to destroy trappers' cabins with what are called lava-flows from fissures. Glowing matter of any kind is always called lava by laymen.

The culminating eruption was an unexpected explosion from the northwestern portion of the interior of the enormous Aniakohak Crater on the Peninsula 45 miles north-northeast from Chignik. This occurred on May 1, 1931, and was studied by Father B. R. Hubbard, who had made fine pictures of the crater the year before which were published in the National Geographic for September 1931. The black cloud rose 20,000 feet, there were heavy falls of bombs, cinders, and ash, there was a succession of eruptions, and extra big ones occurred on May 11 and May 20. There was the usual darkness and the detonations were heard 200 miles away. There was much loss of life among wild animals. The explosion vent exhibited a new lava-dome like Novarupta at Katmai. The whole country was covered with ash and greatly changed in appearance.

Other Aleutian eruptions were outbreaks of Tulik Volcano at the east end of Umnak Island March 21, 1931, sending up thick black smoke. Bogoslof was fiery October 31, 1931. Mount Cleveland started eruption again about January 1, 1932, sending up seven great puffs of black fume in an hour. The exquisite cone of Shishaldin broke out February 1, 1932, and this eruption was described as the most violent and spectacular seen in the past century for this volcano. Glowing material slid down the sides, and the volcano was still hurling up hot rocks and sending ash many miles to leeward on February 16, 1932.

In Java an important eruption of Merapi (central Java) started November 25, 1930, and continued exuding lava of a stiff, blocky variety throughout much of 1931. Except for the volcano on Bali, the flowing of lava is rare in the Dutch East Indies, though the lift of andesitic domes within craters there is well known. There had been an increase of tremors from January to May at Merapi, and the temperature of the solfataras was about 600° C in October, but this was not unusual for this place. In November large and small tremors increased, explosions were heard November 23 and continued, and when the glowing lava appeared November 25, large tremors caused by crater avalanches came to an end. The lava was very tough and irregular in flowing, variably glowing, with rough blocks falling from the front which burst and formed small clouds mixed with the general cauliflowerers of the eruption. This flowing with small gas-concentration continued until December 18, 1930. Then big blasts occurred, throwing out old material mixed with fresh lava, and these took the form of hot blasts similar to those of Pelée, emerging from a big deep chasm formed in the slope of the mountain below the summit crater. Great avalanches and streams of blocks rushed down and followed valleys along with a drifting cloud of sand, ash, and gas. While the debris followed the ravines, the whirling hot sand-clouds would keep their own direction and make fearful destruction. The largest such "nuée ardente" descended December 19, killed more than 1,300 people, devastated 22 square kilometers of country, and spread more than 10 kilometers from the center. The stream of debris in the valleys was 10 to 60 meters thick, and the sand covering beyond was one to 40 centimeters thick. There had been lava-domes on the summit of Merapi east and west, which collapsed December 19, and after a succession of hot blasts thick lava rose again which formed a new dome in the chasm somewhat away from the center of the mountain.

In January 1931 lava issued from various parts of this lava-dome, blocks fell noisily from the crust as the dome repeatedly burst, and the mud and debris slides in the valleys (lahars) solidified and cooled, the rains making water explosions against the hot material just as at Soufriere and Pelée in 1902. The rivers carried quantities of sand. Light seen above the lava-dome was probably flame from burning gas, appearing as fumarolic action in daytime. Sulphur dioxide was strong and temperatures of some known fumaroles, formerly 500°C , had lowered to 60°C . On the other hand, fumarole action had spread out. On March 25, 1931, there was an older lava-stream of 1930 from the gash under the summit, and a younger one which gushed out on March 10 and increased after March 15, so that on March 19 the lava tongue was 180 meters lower than the week before. There were many small hot blasts, with much avalanching, and glowing spots on top of the dome marked places where lava was gushing. Erosion was now etching rill patterns rapidly in the deep, hot, debris fills of the valleys, with mud geysers thrown up 50 meters in places, where the eroding streams came in contact with the almost incandescent lower beds. Temperatures were measured up to 280°C . The fumarole activity at the head of the Senowo River, which had measured 610°C in October 1930, had ceased altogether in April 1931. Lava flowing and hot blasts continued in May and June 1931, and a new local observatory was built four kilometers from the summit at elevation 1,279 meters on the northwest slope of the mountain, equipped with a tunnel, in the end of which a seismograph was placed, this tunnel providing a safe refuge against hot-blast downrushes. In July and August 1931 lava-flow and avalanches continued, and low-temperature glow could be seen in the crater, where in daytime dense vapor arose.

In Hawaii the present cycle of activities, which began in 1924 and has been marked by approximately annual outbreaks of lava rising in the bottom of Halemaumau pit at Kilauea Volcano, and by one long lava-flow from Mauna Loa in 1926, was continued by another inflow on the bottom of the fire pit of Kilauea beginning December 23, 1931, and ending January 6, 1932. The volume of inflow was 332 million cubic feet of basaltic lava covering about 80 acres of the bottom of Halemaumau to a depth of 115 feet above the floor of 1930, leaving the pit 855 feet deep. The phenomena were a sudden rupture athwart the 1930 floor of a straight fissure on the line of the southwest rift of Kilauea Mountain, gigantic gas fountains of pumiceous slag emitting a big volume of sulphur dioxide gas noisiously intolerable at the edge of the pit for the first 12 hours, then a settling down to a line of fountains with radiating bright lines in the lava-lake which covered the whole bottom, and finally a single vent which had built a big cone from which lava-streams poured over the floor. The nature of the activity was quite like the eruptions of 1924, 1927, 1929, etc., all of them different from the activities of the last cycle which centered about 1919. The difference is seen in the much more frothy character of the lava spouting, with fountains often 400 feet high flinging basaltic pumice, all of which is characteristic of the Mauna Loa eruptions in distinction from the heavier slaggy flings and pahoehoe flows of Kilauea in the nineteenth century and later. Kilauea, in other words, has somewhat changed its habit to a Mauna Loa type of action since the vast engulfment of the steam-blast eruption of 1924, which is worthy of pondering for its theoretical meaning.

If the value of science is measured by its ability to predict, volcanology is improving. There was a series of measurements tending to forecast the recent outbreak of Kilauea. Besides the expectable interval of about a year, there was accumulated tilt measured by seismographs, away from the center, suggesting upward pressure. There was a week of excessive tremors and earthquakes ten days before the outburst. There was opening of measured cracks along the rim of Halemaumau pit by unusual amounts, as though the dome of the Kilauea floor around the pit were swelling up. This led to an avalanche of rim-block material back to one of these cracks on December 7. There was a strongish earthquake December 13 when along this southwest rift on the Kilauea Mountain flank there were rumbling noises and sounds of slabs falling down cracks, heard by Park rangers in the desert. Finally there was an unusually strong shock on this same rift, within the crater, three hours before the eruption began. Accompanying the eruption there was steady harmonic tremor which started and ceased in coincidence with lava-inflow. At the Observatory on the edge of the greater Kilauea Crater, where tilt accumulation had tended away from the center, there was sudden inward or centripetal tilt as soon as the escape of gas and lava relieved the upward pressure. In the annual reports made by the Volcano Observatory to the Director of the Geological Survey, experimental predictions based on such evidences have been written down every year. For the fiscal year ending June 30, 1932, the words were,

"There is every reason now for the Observatory staff to be prepared for eruption from both Kilauea and Mauna Loa in the near future, and almost certainly from one of the two during the fiscal year 1932. The eruption came in exactly the middle of the fiscal year 1932, and as there is expectation for this century of Mauna Loa lava-outbreak once in four years, an eruption from that volcano is still expected in addition to the Kilauea release. The whole series of Kilauea eruptions, seven Halemaumau inflows in seven years, marks an upward pressure accumulating, and measured by both leveling and clinometry. These eruptions have increased in volume and effervescence, with the last two outbreaks the most enduring. The culmination of an eleven-year cycle should be within eight or nine years after 1924 for the Hawaiian volcanic system, and should be accompanied by a Mauna Loa outburst.

About the beginning of 1931 four remarkable earthquake-disasters occurred in volcanic lands. These were in the Izu Peninsula south of Fujiyama in Japan November 26, 1930, at Oaxaca in southern Mexico January 14, 1931, at Napier in the North Island of New Zealand February 2, 1931, and at Managua in Nicaragua March 31, 1931. Three of these destroyed cities, and all were within a hundred miles of active volcanoes. The disaster in the Izu Peninsula wrecked portions of the same district that was the center of the terrific Tokyo earthquake of 1923, shaking down landslides in the Hakone Mountains near Myanoshita and Atami, places of solfataras and boiling springs, actual foot-slope volcanoes of the Fuji system. Many people were killed. At Oaxaca, which is somewhat on the same line of volcanic fractures as Managua, only farther west, 65 people were killed, a great part of Mexico was shaken, Popocatepetl revived, and there was reported submarine volcanic activity in the Pacific. At Napier, only 60 miles east of the Taupo active volcanoes, one of the great disasters of earthquake-history occurred, followed by fire, as all the world knows. And finally Managua, right in the volcano-belt of the lake where it is proposed to build a new interoceanic canal, produces an extraordinarily sharp and highly localized earthquake of high intensity, not so much a world-shaker as the others. It may be added that on December 24, 1931, a big earthquake shook the volcanic-island belts of the southwest Pacific near the Solomon Islands, one of the most continuously active volcano-districts on the globe. A tidal wave spread out across the Pacific and was recorded on all tide-gauges. The striking thing about such a series of very large and deep earthquakes, close to belts of volcanoes, is that there must be some relation between the magma that moves under isostatic adjustment and intense seismic movement.

Publications of the year are led by John R. Freeman's great book which has just appeared, entitled "Earthquake damage and earthquake insurance." While this is not volcanologic, it must be mentioned as it is peculiarly timely with reference to the seismic catastrophes in volcanic lands. A book edited by A. L. Day was published as Bulletin 77 of the National Research Council, "Physics of the Earth: I, Volcanology," with three chapters dealing respectively with the geography of volcanoes, by Sapper, the condition of volcanology, by Friedlaender, and the mechanism of volcanoes, by Jagger. A small book entitled, "Volcanoes" in the Home University Library of Thornton Butterworth, Ltd., London, was written by G. W. Tyrrell, lecturer in geology in the University of Glasgow. It is a readable book with the subject approached geologically, but with recognition of modern process measurement. A thoughtful essay on lava-domes by Howel Williams is very comprehensive and well done (Bull. Dept. Geol. Sci., Univ. of Cal., v. 21, Berkeley, 1932).

With reference to new organization of the Volcanologic Section of the U. S. Geological Survey, the appropriations were increased by two-thirds for the fiscal year 1932 with T. A. Jagger in charge, and the Hawaiian station headquarters. E. G. Wingate and A. E. Jones were added to the staff as engineer and seismologist, respectively, both being stationed in Hawaii. The organization was subdivided with Jagger specializing on volcanology of Hawaii and on general administration; E. G. Wingate in charge of seismology of Hawaii, specializing on leveling and tilt, and A. E. Jones in charge of seismologic instruments and records of earthquakes; H. A. Powers in charge of volcanologic surveys of Hawaii and petrology; and R. H. Finch in charge of volcanology in the northwestern United States and Alaska. The Hawaiian Volcano Research Association continues to cooperate in the Hawaiian work. The Lassen Volcano Observatory maintains three seismograph stations. There are two in the Aleutian belt, at Kodiak and Dutch Harbor.

U. S. Geological Survey,
Volcano House, Hawaii

BLANK PAGE

CONTENTS

	PAGE
SECTION OF HYDROLOGY.	275
Annual reports of permanent committees for 1931-32	277
On the hydrology of Snow. J. E. Church, Chairman	277
The Adirondack Snow-Survey, winter of 1931-32. E. S. Cullings	280
On glaciers. P. E. Matthes, Chairman	282
On evaporation. Geo. F. McEwen, Chairman	287
On absorption and transpiration. Charles H. Lee, Chairman.	288
On runoff. L. K. Sherman, Chairman	298
On underground water. David G. Thompson, Chairman.	298
Hydrological investigative work by petroleum companies. Parker D. Traak	306
Investigations of underground-water problems in Arizona, California, New	
Mexico, and Oregon. Arthur M. Piper.	308
On dynamics of streams. L. G. Straub, Chairman	310
On chemistry of natural waters. C. S. Scofield, Chairman	312
Papers	313
Recent investigations of Thiem a method for determining permeability of	
water-bearing materials. L. K. Wenzel	313
Equation for lines of flow in vicinity of discharging artesian well.	
Charles V. Theis	317
Characteristics of runoff of southeastern Alaska. Fred F. Henshaw.	320
Certain flood-flow phenomena of Iowa rivers. Floyd A. Nagler	322
Forces acting on soil moisture in relation to other fundamental functions.	
N. E. Edlefsen	328
The disposal of moisture from the aerated portion of soils. P. J. Vaih-	
meyer.	330
The relation of hydrographs of runoff to size and character of drainage-	
basins. LeRoy K. Sherman.	332
Velocity of flow in natural streams. H. K. Barrows	339
Drainage-basin characteristics. Robert E. Horton	350
The 1929 floods on eastern North Carolina streams. Thorndike Saville	361
Investigations of the fluctuations of water-levels in observation-wells in	
Virginia. R. C. Cady.	370
Investigations of the fluctuations of the ground-water table in Pennsylv-	
vania. S. W. Lohman	373
Hydraulic and sedimentary characteristics of rivers. L. G. Straub.	375
New thoughts on river regulation. Gerard H. Matthes.	382
Model research in the river hydraulic laboratory of the Massachusetts In-	
stitute of Technology. J. B. Drisko	384
Present status of the National Hydraulic Laboratory. K. Hilding Beij	387
New formulae for predicting annual runoff of some California watersheds.	
A. F. Gorton	388
Rainfall- and runoff-characteristics of the Delaware River Basin. Clarence	
S. Jarvis.	388
Checks on the model law for hydraulic structures. Morrrough P. O'Brien.	390
A method for computing the amount of evaporation of sea-water from a tank	
by changes in salinity, with experimental results obtained on board the	
Scripps August 13-24, 1928. Burt Richardson	394
Problems of underground water-flow in the oil industry. Morris Muskat.	399

ANNUAL REPORTS OF PERMANENT COMMITTEES FOR 1931-32

ON THE HYDROLOGY OF SNOW

J. E. Church, Chairman

The report of this first year of activity must necessarily be one of organization and ideals rather than a final report on any piece of work accomplished.

The field--To accomplish the largest possible service, the field of the hydrology of snow has been broadened beyond the narrower limits of the economic aspects of snow-fall and runoff to include the evolution of snow from its initial fall until its final emergence at the mouth of the stream. This will also necessarily include rainfall- and evaporation-studies so far as they have a bearing on the forecasting of stream-flow.

That the subject may be seen in its broadest aspects it is planned to include all studies made not only in the United States but other countries as well and also in the polar regions.

Personnel--Committee members have been chosen primarily because of their interest in snow- and ice-research, secondarily because of their association with large snow-survey projects from which will come the problems and the basic material for their solving, and finally because of their regional location. The members of the Committee are listed in the prospectus issued by the Section of Hydrology under date of April 1, 1932.

International--Despite the continued illness of Prof. Barnes, his name has been included in the personnel of the Committee on Hydrology of Snow because of his high standing in ice engineering and in the hope of future service. However, this action has been taken without consultation with him and in tribute to his years of enthusiastic endeavor under physical handicap.

Mathew Balls has consented to serve under such cooperation as the Canadian National Committee on Geodesy and Geophysics and the American Geophysical Union may arrange.

Prof. Hobbs will represent the Committee viewpoint on the International Commission of Glaciers, which seems to be the only international body representing ice and snow.

Support--The activities of the Committee are made possible by the cooperation of the Nevada Agricultural Experiment Station, pioneer in snow-surveying, which furnishes both clerical and financial assistance in all routine work and in some of its projects.

Projects--Two main projects have been organized, namely, a Questionnaire regarding present activities in snow-surveying and forecasting stream-flow, and a Bibliography of all publication in the broad field of snow and ice. From these two projects will be obtained the material facts and the parties desiring them. In this way the Committee hopes to become a clearing house of information and guidance.

1--Questionnaire

(1) **Mailing list**--Approximately 1,600 copies of the Questionnaire have been sent to the following groups: Committee on Hydrology of Snow of American Geophysical Union; all members Section of Hydrology of American Geophysical Union; district engineers, United States Geological Survey; engineers and project managers, United States Reclamation Service; officials, including supervisors and district rangers, of the United States Forest Service; officials and section directors, United States Weather Bureau in snow-sections of United States; deans of engineering schools in United States and Canada; representative power companies, especially hydro-electric companies; city engineers of larger cities in snow-sections of United States and in Canada; members of International Glacier Commission; representative consulting engineers; foreign power companies; agricultural experiment-station directors; foreign universities and technological schools; Departments of Streams and Forests of foreign countries; all persons or organizations recommended by the recipients of the Questionnaire.

(2) Points of information--The points on which information was desired are best presented by the Questionnaire itself issued by the Committee on behalf of the Section of Hydrology of the American Geophysical Union of the National Research Council as follows:

Questionnaire on the hydrology of snow

- 1--Are snow-surveying and forecasting of stream-flow practiced in your region?
 - (a) What persons or organizations are in charge? (Please give addresses)
 - (b) What publications have been issued?
 - 2--Do you know of any research problems completed, under way, or planned?
 - (a) Snowfall
 - (b) Snowcover
 - (c) Evaporation, especially of snow
 - (d) Runoff, including floods
 - (e) Ice
 - 3--What colleges are giving courses in general hydrology? Which ones are including the hydrology of snow?
 - 4--What organizations, officials, or persons in your region or elsewhere would be interested in the problem of snow and ice? (Please give addresses also)
 - 5--What general or special sources for obtaining information on the above or related topics would you suggest?
 - 6--What suggestions regarding the furthering of this inquiry or regarding general Committee activity would you yourself offer?
- Note--Please give full details and mail to Chairman of Committee at address given below.

Owing to shortness of time before annual meeting of American Geophysical Union, an early reply is essential.

(Signed) J. E. Church, Chairman of Committee,
Nevada Agricultural Experiment Station
Reno, Nevada, U. S. A.

(3) Returns--For the 1,500 questionnaires mailed out, 300 answers have been received. These are distributed as follows:

1--New England	16
2--Northeastern United States (including all states east of the Mississippi and north of the Ohio, except New England)	54
3--Southeastern United States (including all states south of the Ohio and east of Mississippi)	20
4--Continental Divide eastward to the Mississippi except Arkansas southward	69
5--Great Basin	13
6--California	36
7--Pacific Northwest (including Idaho and Alaska)	44
8--Southwestern United States (including all states south of Missouri and west of the Mississippi)	30
9--Canada	9
10--Foreign and polar	9

The time has been too short to make a detailed analysis of the replies, which should preferably be reserved for a special report. However, certain generalizations can be mentioned.

(4) Snow-zones--On the basis of effective snow-cover, the United States and Canada are divided into two zones, the dividing line running along the Ohio River and northern boundary of Arkansas through Arizona.

In the southern zone the snow is neither sufficiently heavy nor lasts sufficiently long to have economic value, and even the mountains affect this situation only slightly.

In the northern, the economic interest in the snow increases with the mountains and becomes greatest in the West where snow accumulation and storage are vitally essential to summer power and crops.

(6) Snow-surveying--As contrasted with rain-gage and snow-board measurements, snow-surveying is an infant but rapidly growing method of forecasting seasonal water-supply.

Though first practiced in Maine, it found its full development in the West, where it has now become a part of the organized state service in Nevada, Utah, Oregon, and California. It is also practiced on the Upper Columbia and the Snake.

In Canada, snow-surveys have been conducted on the head-waters of the Bow River, and at present are being conducted on the head-waters of the St. Mary River, Winnipeg River, and in the Gatineau River and St. Maurice River water-sheds. Snow-surveying is also reported as being conducted in British Columbia and planned for the Nipigon River and Abitibi River basins.

In New York, the snow-survey established in the Black River Regulating District has become a large cooperative effort covering the Adirondacks.

A large effort, still in the preparatory stage, is proposed by the United States Reclamation Service for the regulating of the Colorado River at Hoover Dam.

(6) Teaching of hydrology--The data so far available do not permit a definite statement regarding the teaching of hydrology, especially the hydrology of snow. Most institutions give only very general courses. A few offer courses highly specialized, as in the geology of underground waters. Some have inquired into the principles of the hydrology of snow for the purpose of giving instruction in it.

An investigation of college and technical-school courses will be necessary to supplement the partial information procured by the Questionnaire.

(7) Research--Research in the hydrology of snow seems to be confined mainly to Utah and Nevada. At the Utah Agricultural Experiment-Station, the problem under investigation is "Snow-cover runoff relationships as a basis for forecasting stream-flow."

At the University of Nevada Engineering Experiment-Station, long-time normals for snow-cover have been established on the basis of stream-flow. At the Nevada Agricultural Experiment-Station, where the Department of Meteorology was recently re-established, a monograph on "Snow-surveying in relation to forecasting stream-flow," the pioneer work on this subject, is being revised and enlarged for early publication. In addition to this, studies have been started on the effect of the alluvial soil and the dams in the bed of the Humboldt River, Nevada, on the runoff of that stream.

In Oregon, J. C. Stevens is developing a seasonal snow-gage on Mt. Hood for use in isolated mountain areas.

(8) Recommendations--The recommendations made can be summed up in spirit in the three phrases (a) unified practice, (b) centralized direction, and (c) detailed information, supported by cooperative effort, all high ideals for the Committee to follow.

Special recommendation was also made that the Bibliography forming the Committee's second project should be completed and a Directory made of organizations and personnel interested in the work.

2--Bibliography of snow and ice

This second project seems basically essential both to research and the distribution of information, and should be made as broad and detailed as possible to afford complete service.

The literature is mainly available only at Washington and much is in Russian. Owing to costs of transportation and time-restrictions on loans, some Committee representative or clerk should be employed to select the books that can best be excerpted by individual members of the Committee. Some linguist scientist should also be temporarily employed.

The question has already been presented to the American Geophysical Union and the Nevada Agricultural Experiment-Station for consideration as a cooperative effort. The possible difficulty will be the interpretation of research work.

The project has already been greatly furthered by the loan of 500 titles by Dr. Charles F. Brooks, gathered by him in connection with other work.

Appendix

Appended to the present report are three papers, not published here but on file with Secretary of the Section, by the Chairman on the history of snow-surveying, and the latest problems. These are: (1) The inside story of snow-surveying, to appear in an early issue of Western Construction News and Highways Builder; (2) Snow-survey problems in the Humboldt Basin, Nevada, reprinted from Humboldt River Distribution, 1932; and (3) Seasonal snow-survey and forecast of stream-flow, March 1, 1932, Nevada cooperative snow-surveys--II Humboldt Quadrangle.

Other publications are the Monthly Bulletins of Snow-Survey and Precipitation Data and Seasonal Forecast, April 1, 1932, issued by California, Utah, and New York. The bulletin by Oregon has no forecasts or predictions.

Hereafter, a complete list of all publications for the year will, so far as possible, be obtained and a collection made for purposes of loan.

Nevada Agricultural Experiment-Station,
Reno, Nevada

THE ADIRONDACK SNOW-SURVEY, WINTER OF 1931-32

E. C. Cullings, Vice-Chairman

In the Black River Regulating District the systematic measurement of the quantity of water stored on the ground in the form of snow was begun in 1926, though occasional measurements had been made at earlier dates. The Hudson River Regulating District joined in the work in 1930, and the Utica Gas and Electric Company and the New York Power and Light Company in 1931. The data thus far obtained on somewhat limited areas indicated the need of a more extended survey covering, if possible, the entire Adirondack Plateau.

A conference of interested parties was held in the early summer, at which representatives of the United States Geological Survey, the State Department of Public Works, the Black River Regulating District, the Hudson River Regulating District, the Utica Gas and Electric Company, the New York Power and Light Company, and the Associated Gas and Electric System were present. It was agreed that the entire region would be covered in future surveys, and each participating party would cover the territory in which his own organization was most directly interested. It was also agreed that all parties should use uniform equipment and notebooks and that uniform methods of work should be followed. It was arranged that surveys should be made about January 1, February 1, March 1, and the latter part of March.

The plan agreed upon follows the methods developed by Dr. J. E. Church of the Nevada Cooperative Snow-Survey with such modifications as have been found necessary to adapt them to Adirondack conditions. Because of the uniformity of depth and the low density of snow in this region, the three-inch snow tube was selected in place of the 1 1/2-inch tube found most satisfactory in Nevada. The weighing scale adopted is a commercial spring-balance, manufactured by Chatillon and Sons, having a total capacity of six pounds in three revolutions at two pounds per revolution. The dial is graduated in 100 equal parts representing 10 inches of water, when the cutting-shoe has a diameter of 2.655 inches. The scale, therefore, has a total capacity of 10 inches of water per revolution, or a total of 30 inches. The weight of the empty tube, however, is equivalent to from 10 to 12 inches of water. Uniform notebooks were provided for each party.

A second conference was held in the fall and all parties were ready to start "full steam ahead" on January 1, but someone--perhaps we can blame the Weather Bureau--played a joke on us, and delayed the beginning of winter from the customary date of early December to the first of March. The past winter was one of the most unusual seasons on record. While the precipitation was above normal every month except February, most of it was in the form of rain and the accumulation of snow up to March 1 was almost nothing. The surveys scheduled for January 1, February 1, and March 1 were cancelled. The Hudson River Regulating District, however, made surveys of the Sacandaga region weekly or biweekly after January 11.

In the Black River Regulating District a system of snow-stakes placed at the principal snow-survey courses was read weekly from the first of January. The average depth at these stations was six inches January 2, three inches January 9, and bare ground January 16. By February first 12 inches had accumulated, and it continued at about this depth until early in March, when a general storm precipitated from one to two feet of new snow. During March a series of storms maintained the snow-depth at from two to three feet, with a gradually accumulating water-content. On April 1, the equivalent depth of water in the central plateau-region was about six inches. Needless to say, we are hoping for better luck next year.

The season of 1930-31 was quite the opposite in weather-conditions. It was a long, cold winter without a thaw from the beginning of winter, late in November, to the spring melting period, which began at the end of March. While the precipitation was far below normal every month, it was almost entirely in the form of snow, which accumulated steadily throughout the winter. The equivalent depth of water on the ground at the end of winter was about 50 per cent greater than in 1932.

The measurement of the accumulated snow is, however, only the first step in the reservoir- and flood-problem. The percentage which will appear as runoff in the streams appears to depend largely on the state of the ground-water. If, as in 1931, the ground-water is exhausted or seriously depleted, the runoff will be low, but if, as in 1932, the ground-water has been replenished by winter rains and thaws, the percentage of runoff will be much higher. The evaporating capacity of the weather during the melting period also appears to have considerable influence on the water-yield of the snow.

Flood-flow to be expected during the spring melting-period is, of course, governed chiefly by the rapidity of melting. Contrary to the popular belief, a period of fair, warm weather, with absence of frost at night, will melt the snow more rapidly than a rain of some magnitude with cool, cloudy weather. It would be interesting and instructive to know the characteristics of the energy-rays which are most effective in converting water from the solid to the liquid form.

More intensive study should be given to the factors which control runoff. The pressure or absence of frost in the ground under the snow is of importance, and should be noted in all snow-surveys. Generally speaking, there is little or no frost under a foot or more of snow in the Adirondack region. A study of temperature, particularly the accumulated temperature above freezing during the melting period, might yield valuable data on the flood-flow to be expected.

Another interesting question is the behavior of the rain which falls on a snow-blanket of considerable depth. Does it remain in the snow or pass quite rapidly through the snow and into the ground? How much rain will be absorbed by a given blanket of snow? What is the relation of density to the absorbing capacity of snow? The phenomena of melting also offer interesting problems. Does the water from the snow melted at the surface trickle through the snow to the ground, or is it held in the snow until the whole blanket reaches maximum density? What is the relation between capillarity and gravity?

Many of these problems are beyond the scope of a snow-survey, the primary purpose of which is intensely practical. The help of the physical laboratory will be necessary for the more abstract problems, but more accurate observation of field phenomena will be of material assistance in eliminating some of the guess-work from reservoir-operation in temperate climates. Whether a reservoir be operated for domes-

tic water-supply, water-power, or flood-control, a knowledge of snow-conditions is essential to a rational plan of operation. The snow-survey, however, should be tied in with accurate observations of stream-flow, rainfall, ground-water stage, and perhaps other hydrological factors.

Black River Regulating District,
Watertown, New York, April 22, 1932

ON GLACIERS

F. E. Matthes, Chairman

The changes in the sizes of glaciers has for long attracted the attention of glacialists on account of the scientific interest and the development of water-power from the streams issuing from the glaciers.

The International Congress of Geologists, at its Zurich meeting in 1894, appointed a committee, with members from many countries, to collect and publish information bearing on this subject. Annual reports were published in the *Archives des Sciences*, Geneva, from 1896 to 1906, after which they appeared in the *Zeitschrift für Gletscherkunde* until the war. It was not until the Prague meeting of the International Union of Geodesy and Geophysics in 1927 that a new Commission des Glaciers was appointed, which is about to resume publication.

The earlier reports were abstracted, and more detailed reports of American glaciers given, in a series of 20 articles on The variations of glaciers, published in the *Journal of Geology*, 1895-1916. It is much to be hoped that information regarding American glaciers since the latter year may be collected in order to tie up the older records with the recent ones.

The American Geophysical Union's Committee on Glaciers (originally designated the Committee on the Hydrology of Glaciers) has the satisfaction of being able to report that during this, the first year of its existence, it has made a start on its main task. This task is to build up a systematic record of the variations in length and volume of the principal glaciers in the United States and Alaska, for the purpose of determining, among other things, the trend of climatic oscillations now in progress and affecting the waters of the continent.

The activities of the Committee have been, in the main, threefold:

First, to enlist the active cooperation of dependable organizations and individuals who by reason of their location in the proximity of glaciers are in a position, without undue expenditure of time or effort, to make annual measurements at the glacier fronts or at least to take photographs of them.

Second, to file the data resulting from the newly instituted glacier measurements.

Third, to study the works already compiled and published by earlier observers for data throwing light on past fluctuations of the glaciers, so that the climatic curves may be extended backward, if necessary, over several decades or even over longer periods and brought forward up to date.

Naturally the main efforts of the Committee at this early stage have been directed towards the first objective, namely, to secure the cooperation of volunteer observers located near the glaciers. These efforts, fortunately, have met with gratifying results from several quarters, notably from the National Park Service and the Forest Service, within whose respective reservations the majority of the more important glaciers in the United States and Alaska are situated; also from the Mazamas, the well-known mountaineering club of Portland, Oregon, which is especially interested in the glaciers of Mount Hood.

At the same time the Committee, soon after its start, found itself in possession of a considerable body of data relating to both recent and past fluctuations of gla-

elers. The National Park Service has been making measurements on the recession of at least one glacier in Mount Rainier National Park for a number of years; the Masamas have been measuring three glaciers on Mount Hood; and several scientists, including members of the Committee itself, have had opportunity within the last few years to make measurements and observations on a large number of glaciers on the coast of Alaska and to compare their present positions with those reported by earlier explorers. In fact, so abundant are the data already in hand that it would be impossible in a brief progress-report, such as this necessarily must be, to cite the figures relating to each individual glacier observed. Such a detailed report the Committee hopes to issue at a later date when funds for its publication will be obtainable.

Glaciers in the continental United States

Mount Rainier National Park--First mention is due the Misqually Glacier, on the south side of Mount Rainier, whose recession has been faithfully measured by the National Park Service in the autumn of every year since 1918, and whose earlier history has been traced from various historical records as far back as 1857, the year of the Glacier's discovery. In spite of the previous declaration that no figures will be cited in this report for any individual glaciers, it seems appropriate to make an exception for the Misqually, which is outstanding among all the glaciers in the United States for the length and completeness of its recession-record and for the thoroughness with which it has been studied in other respects. Its continued recession, moreover, is a matter of economic concern, as the electric-light plant of the city of Tacoma depends for power on the flow of the Misqually River. The table below is furnished by the National Park Service. (Note that for the periods 1857-85 and 1885-92 the estimates are based on historical records.)

Years	Recession in feet	Years	Recession in feet
1857-1885	780	1923-1924	83
1885-1892	140	1924-1925	73
1892-1918	1310	1925-1926	86
1918-1919	59	1926-1927	43
1919-1920	46	1927-1928	89
1920-1921	106	1928-1929	52
1921-1922	67	1929-1930	118
1922-1923	44	1930-1931	49

It will be seen that since 1918 the Glacier, which then had a length of nearly five miles, has been shortened 915 feet. The total shortening since 1857 amounts to 3,125 feet.

To ascertain what this shortening might imply as to reduction in the Glacier's volume and in the flow of the Misqually River, an elaborate investigation is now being made by a group of engineers representing the city of Tacoma, the Water Resources Branch of the United States Geological Survey, the National Park Service, and the Bureau of Public Roads, under the leadership of Mr. Llewellyn Evans, Superintendent of Light of Tacoma. This investigation has required the making of a map of the lower course of the Glacier by plane-table and stadia on a scale of 4,000 feet to the inch and with 20-foot contours. Comparison of this detailed map with the small-scale map made by the United States Geological Survey in 1910 indicates a loss of ice amounting to 20,000 acre-feet in 21 years. The consequent reduction in the summer flow of the River is estimated at 10 per cent.

From the age of the bushes and trees in the successive zones of vegetation on the sides of the canyon flanking the Misqually Glacier, it has been ascertained that the last great advance of the Glacier occurred in or prior to 1850. The diminution in the volume of the lower portion of the Glacier since that date is estimated, roughly, at 300,000 acre-feet, and the consequent reduction in the summer flow of the River is estimated to have been of the order of 50 per cent. Truly amazing figures.

Other glaciers in the Mount Rainier National Park that are now being measured annually by the National Park Service are the Emmons, on the northeast side, the South Tahoma, on the southwest side, and the Paradise, on the southeast side.

Yosemite National Park--In the autumn of 1931 base-lines were laid out in front of the Iyell and McClure glaciers, and initial measurements were made to each of these ice-tongues. The same was done for the Dana Glacier, which lies just outside of the boundary of the Park.

Of the greatest interest perhaps to the general public, as well as to scientists, is the announcement made by Park Naturalist, C. A. Harwell, that the little cirque glacier under Merced Peak, which was the first "living glacier" to be discovered by John Muir, in 1871, has ceased to exist, only the moraines remaining to attest its former presence. Observations by F. W. Matthes, of the United States Geological Survey, on fresh moraines in empty cirques in the Yosemite National Park and adjoining portions of the Sierra Nevada, point to the probability that hundreds of other small cirque glaciers have similarly vanished from the range during the last 50 or 60 years.

Other national parks--Definite plans have been made by the National Park Service this year for the laying out of base-lines at the fronts of 20 different glaciers in Rocky Mountain, Grand Teton, and Glacier National parks.

Wind River Range--Observations by Professor C. K. Wentworth, during the summer of 1930, on several glaciers of the Dimwoody group, in the vicinity of Gannett Park, indicate that these glaciers have lost appreciably in length and volume since 1906, the year when they were mapped by the United States Geological Survey.

Mount Hood--Measurements by the Research Committee of the Mazamas on the Eliot, Coe, and Ladd glaciers show that these small ice-tongues have lost on the whole but little in length and volume during the past four or five years. They have lost probably less in proportion to their total length and volume than the large glaciers on Mount Rainier.

While these small ice-tongues on Mount Hood seem insignificant compared with the large glaciers on Mount Rainier, they may prove in the long run more profitable subjects for study, for short glaciers in general respond more promptly to variations in snowfall and temperature than long glaciers, and their fluctuations therefore are likely to afford a truer index of climatic changes.

Of paramount interest is the reported discovery by the Mazamas of a tangled mass of logs protruding from under a moraine of the Zigzag Glacier, on the southwest side of Mount Hood. Evidently a forest of tall, straight trees grew here at an altitude corresponding approximately to that of the present timber-line, and then was overwhelmed by the Zigzag Glacier during a recent advance. This discovery focuses the attention upon closely similar observations that were made on the south side of the peak in 1906 by A. H. Sylvester, who then was engaged in mapping Mount Hood for the United States Geological Survey. Sylvester found another buried forest, with soil and stumps still in place, at the head of White River Canyon.

While there may be room for differences in interpretation, it seems altogether probable that these ancient forests grew on the sides of Mount Hood at a time when the climate was much milder and rainier than now, and when the glaciers either were confined to the summit of the peak or had vanished altogether. Corroborative evidence of such a period of mild, rainy conditions in the Pacific Northwest, which preceded the conditions now prevailing at the higher altitudes, was found more recently by Sylvester on the northern part of the Cascade Range. This evidence consists of remnants of a forest of great columnar trees, many of them five or six feet in diameter, that occur up to the level of the present timber-line. As Sylvester points out, glaciers could not have existed on the Cascade Range at the levels at which they now occur, during the thousands of years of mild, rainy conditions indicated by the large trees; therefore, it would appear that the present glaciers on the range (with the exception, probably, of the larger ones on Mount Rainier and the other great volcanic peaks) have come into existence within the last few centuries and are not survivals from the glacial epoch.

While these matters may seem to go farther back into the past than the investigations of the Committee on Glaciers perhaps were intended to be carried, they so fundamentally affect one's conceptions of the climatic oscillations that have occurred in the recent past that they can hardly be neglected. The problem is one in which the

expert forester can materially assist the geologist, and it is the intention of the Committee, therefore, to appeal to foresters in the western states and Alaska to look for further evidence bearing upon it.

Alaska--It is a fortunate circumstance that the great glaciers of the southern coast of Alaska have drawn the attention of scientists again and again during the past 70 years, for as a result of these repeated visits valuable data are now at hand relating to the advances, recessions, and the varying thicknesses of these glaciers.

Observations and reports concerning the glaciers of Alaska have been made from as early as the latter part of the 18th century to the present date. Such reports have been made by Russian, British, French, Spanish, and American explorers. Among the American contributions are those of Ivan Petroff, I. C. Russell, W. H. Dall, G. F. Wright, George Davidson, Alfred H. Brooks, G. K. Gilbert, H. F. Reid, U. S. Grant, and others too numerous to mention in this report.

The maps of the United States Geological Survey, International Boundary Commission, Coast and Geodetic Survey, and others contain permanent records of great value. Observations by federal geologists, college professors, railway engineers, army officers, and other investigators have added much to the fund of information. Aerial photographs taken by the Alaska aerial expeditions of the Navy of 1926 and 1929 furnished valuable and extensive data concerning the fronts of most of the large glaciers of southeastern Alaska.

Several excellent papers treating of glaciers and glaciation in Alaska have been published. Among the outstanding ones is the series on Variations of glaciers in Alaska by H. F. Reid of Johns Hopkins University, the one on Glaciers and glaciation in Alaska by Alfred H. Brooks (*Alpina Americana*, No. 3, pp. 9-13, 1914), that by S. R. Capps of the United States Geological Survey (Prof. Paper 170-A, 1931), and a comprehensive correlation and study of all available existing knowledge concerning glaciers in Alaska which was set forth in "Alaska glacier-studies" by R. S. Tarr and Lawrence Martin and published by the National Geographic Society in 1914. This book of 500 pages was not only the result of extensive research but of seven seasons in the field. Several hundred citations of the publications of various scientists are made.

It is the purpose of this Committee to eventually assemble and bring down to date the data already available and to secure and correlate all of the information possible in the future. Neither the time allotted for the reading of this paper nor the space allowed for the printing will permit of a complete reference to all of the available data and the authors but it is hoped that in a subsequent report such a complete summary may be given.

Glacier Bay--The first identified observations on the ice-tongues of Glacier Bay were made by Lieutenant Whidbey of Vancouver's expedition in 1794. Between that time and the present, notable contributions have been made by C. E. S. Wood, John Muir, G. W. Lamplugh, G. F. Wright, I. C. Russell, G. K. Gilbert, Henry Gannett, B. K. Emerson, R. S. Tarr, Lawrence Martin, William S. Cooper, Wm. Osgood Field, and others. Important observations have been made from time to time by members of various international boundary-survey parties, and the latest study of the area was made during the summer of 1931 by H. F. Reid and C. W. Wright, members of a United States Geological Survey party, both of whom had made previous extended detailed observations of the glaciers of the region. The results of this expedition have not been published.

Comparison of the position of the glacier-front and the thickness of the ice-masses as determined by the different expeditions reveals oscillatory movements since the first.

Among the tidal ice-tongues the Muir Glacier notably has receded approximately 12 miles since 1879, the Grand Pacific and Johns Hopkins glaciers approximately 17 miles each. On the other hand, the Carroll, whose terminus is now on land just off shore, has receded very little. Fairly definite data are available for 12 other glaciers in this region.

Glaciers near Juneau--For several years a record has been kept of the recession of the Mendenhall Glacier, near Juneau, by M. L. Merritt, Assistant Regional Forester for Alaska, and others. Aerial photographs of the Taku Glacier were taken in 1926 and 1929 by aerial survey expeditions of the Navy and in 1931 by C. W. Wright. The Mendenhall, Taku, Herbert, and Morris glaciers, further, were photographed from the land in 1931 by C. K. Wentworth and L. L. Ray.

Prince William Sound--The glaciers of the north side of Prince William Sound which come down from the lofty Chugach Range were studied in a comprehensive manner by the Harriman Alaska Expedition in 1899. They were subsequently revisited at frequent intervals until 1914 by a number of expeditions notably Grant and Higgins, B. F. Johnson, Mrs. Dora Keen Handy, and Tarr and Martin whose report has already been mentioned.

In 1931 a comprehensive reexamination of these glaciers was made by Wm. B. Osgood Field, Jr. He relocated many of the old transit and photographic stations and established new ones. The glaciers covered by his survey are practically all the major ice-tongues on the northern side of Prince William Sound.

C. K. Wentworth and L. L. Ray also visited Prince William Sound and the lower Copper River and took photographs of many of the glaciers along the Copper River Railway.

By studying all of the photographs and data that can be secured from the earlier expeditions, the Harriman, Grant and Higgins, and the historical summaries, detailed field observations, and topographic maps of Tarr and Martin, Mr. Field has undertaken the task of supplementing the excellent work of the other explorers in a study of the history of the fluctuation of each of the glaciers measured by him. The glaciers of Prince William Sound have behaved variously, some making notable advances, others remaining essentially stationary and still others advancing and retreating in alternation. For example, the western portion of the front of the great Columbia Glacier was found in 1909 to have pushed into a forest that had grown undisturbed. This advance continued intermittently till after 1914 at which time it was about 1,800 feet beyond its position in 1899. Since this maximum the ice-front has retreated over 900 feet and in September 1931 was again advancing several inches a day.

No attempt will here be made to outline the fluctuations of the other glaciers, nearly every one of which has had a different history. Be it stated merely that five of the large and five of the small glaciers have retreated since 1914; that two other large glaciers are now longer than they were in 1899, 1910, and 1914, but apparently stationary at the present time; and that two more large glaciers, the trunk ice-streams of their respective fiords, are now advancing over ground not occupied by them for more than a century.

Other areas of Alaska, notably Wrangell Mountains, Lower Copper River region, Mt. McKinley region, and Canning River region have all received more or less attention and areal data are available.

It is hoped that in a later and more comprehensive report these data may be correlated.

Plans for future observations in Alaska--Certain members of the Forest Service, the Park Service, and the United States Army in Alaska have signified their willingness to secure annually for the Committee photographs taken from definitely located stations of some twenty-odd glaciers in Alaska, including those about Glacier Bay and the vicinity of Juneau.

Several other residents of Alaska have also offered to secure annual data for the same purpose.

Conclusion--In conclusion, it should be pointed out that the task upon which the Committee has set out necessarily involves the collecting and filing of large numbers of photographs and maps every year. In addition it will soon be in possession of the extensive collections of photographs made by the earlier expeditions. Through the efforts of Mr. Field the Committee has already obtained the extremely valuable collection

of the Harriman Alaska Expedition, which was presented to it by Dr. C. Hart Merriam. Another collection has recently been offered the Committee by Mrs. Dora Keen Handy, and still others may be contributed or secured by different members of the Committee. How and where to house this constantly-growing collection soon became an urgent problem for the Committee to solve. Fortunately, through the good offices of a member of the Committee, a suitable place has been found for them in the Division of Maps at the Library of Congress, and there they will be placed on deposit, as the property of the Committee.

U. S. Geological Survey,
Washington, D. C.

ON EVAPORATION

Geo. F. McFwen, Chairman

Establishment of the Committee and its membership--This is one of several committees of the Section of Hydrology which was recently organized to promote investigations in all phases of the field of hydrology. General information regarding the Section is presented in the report of the executive committee issued April 1, 1932. The work assigned to this Committee relates to the rate of evaporation from free-water surfaces, the effects of weather and other conditions that influence evaporation, and the methods of determining evaporation. It also includes the subject of the fluctuations of lakes and their causes. It touches most closely the field of the Committee on Absorption and Transpiration.

Selection of members of this Committee was based upon the obviously desirable purpose of having widely different sections of the country and different interests and points of view represented. At the same time it was thought best to keep the membership within a rather small limit. The membership of the Committee is listed in the prospectus issued by the Section of Hydrology under date of April 1, 1932.

Letter from the Chairman to members of the Committee--After the Committee was formed, a letter under date of March 18, 1932, was sent to each member for the purpose of organization. Extracts from this letter follow:

"There is enclosed a reprint from Transactions of the Twelfth Annual Meeting of the American Geophysical Union, May 1, 1931, together with a Preliminary Announcement relative to the Section of Hydrology, 1931, and a Preliminary Outline of Activities of the Committee on Evaporation.

Tentative outline on evaporation from free water-surfaces

- (1) Fundamental physical theories of evaporation and resulting formulae for computing evaporation.
- (2) Practical formulae for estimating evaporation from available data on factors presumed to determine it. (These formulae may be more or less empirical and subject to certain limitations, as to conditions and precision.)
- (3) The evaluation and interpretation of existing evaporation-measurements.
- (4) The kind of observations and the instrumental equipment for evaporation-investigations. (This involves the important question of the standardization of methods.)
- (5) Information regarding persons or organizations conducting evaporation-investigations.
- (6) Compilation of a comprehensive bibliography on evaporation.
- (7) Study of special problems, involving evaporation, that may be submitted by others in connection with either scientific investigations or engineering design.

Suggestions relative to this outline will be welcomed from each Committee member, and titles of papers prepared for presentation at the April meeting are desired as soon as possible.

Summary of replies to the above letter--Replies to the letter indicated a general agreement to the provisional outline submitted. The need was stressed of additional experiments for determining coefficients applicable to different types of pans for obtaining the evaporation from large free water-surfaces. Slight called such a coefficient the reservoir-equivalent. Although much good work of this kind has been done, similar experiments should be carried on using older types of equipment in order to interpret extensive records made in the past.

Attention was called to observations being made in New Jersey of water-temperatures in an evaporating pan and corresponding air-temperatures. Such data may lead to correlations that should serve to correct empirical evaporation-formulas based upon air-temperatures.

A question was raised as to reducing evaporation by means of a thin layer of oil. How would this effect the water-temperature?

Scripps Institution of Oceanography,
La Jolla, California

ON ABSORPTION AND TRANSPIRATION

Charles H. Lee, Chairman

The Committee on Absorption and Transpiration was appointed in October 1931 and commenced functioning immediately thereafter. The subjects which have been assigned have nothing in common from the physical or chemical standpoint, their interrelation being based entirely on close sequence in hydrologic processes. Past research in these subjects has been undertaken by differing types of organizations, with diverse technical background and special objective, and there has been little coordination. As a result, fundamental concepts, observational methods, character of auxiliary data, and the form and character of results have been governed by the ideas of the individual investigator, and there has been little standardization. Original research in these subjects has been active in recent years and many important research projects are now in progress. It is thus evident that the Committee has undertaken its work of correlation and coordination not only in diverse and virgin fields, but in ones where there is much existing material to be assembled. These conditions and the short time available for organizing its work are offered in explanation of the sketchy character of this report with its incomplete descriptions of important research work and evident omissions. If the report serves to bring information of other research activities to the Committee, it is felt that a valuable result will have been obtained.

The work of the Committee relates to (1) the absorption of rain, melting snow, and standing or flowing surface-water into the Earth, including its penetration to the water-table; (2) the discharge of water from the Earth by evaporation from the soil and by the transpiration of vegetation; and (3) the effects of absorption and discharge upon groundwater-levels and the flow of springs and streams. In order to definitely define the limits of its work, contact has been made with other committees of the Section of Hydrology, such as Physics of Soil Moisture, Runoff, Evaporation, and Underground Water. The scope of the Committee's work has been outlined so as to overlap the work of other committees no further than necessary to permit a rounded treatment of the subjects assigned.

The energies of the Committee thus far have been devoted to assembling information regarding the research interests and accomplishments of its members, listing and contacting other workers in these fields of hydrology, preparing working definitions of terms pertaining to its work, compiling a bibliography, and obtaining information regarding recent or current research work. These various activities are still in progress and the final productive results will be the subject of future papers and reports. This report contains a brief statement of fundamental concepts and a review of information which has been assembled to date regarding important investigations completed or now in progress.

Absorption

Absorption is defined as the process by which water enters and is taken into the lithosphere. It is actuated by any of the following forces acting singly or in combination: Molecular attraction, capillary pressure, gravity, hydraulic pressure. It includes both absorption from the atmosphere occurring either as inflow of atmospheric water-vapor with condensation, or as hygroscopic absorption; and absorption from the hydrosphere occurring (1) as capillary migration through capillary films into a soil-column with moisture-content less than field capacity, (2) gravity-flow through capillary films into a soil-column with moisture-content exceeding field capacity but less

than saturation, (3) gravity-flow into the interstices of a soil-column which is saturated, (4) influent seepage into a soil-column which is saturated, and (5) free gravity-flow into sink holes or other large openings. In the above statement the hydrosphere is assumed to include both water-films and shallow pools upon the surface of the lithosphere produced by precipitation, and also standing or flowing bodies of surface-water. Seepage is defined as movement under hydraulic pressure, in other words percolation, through the surface of the lithosphere.

Water is absorbed temporarily when it reaches only the belt of soil-water or the intermediate belt of the zone of aeration and later is drawn back therefrom and escapes into the atmosphere by evaporation from moist soil or transpiration of vegetation. Water is absorbed permanently when it penetrates downward to the zone of saturation and becomes an increment of groundwater.

From a practical standpoint, the amount of water absorbed from the atmosphere is negligible. The quantitatively important phases are absorption from precipitation, either as rainfall or melting snow, and absorption from free surface-water occurring as natural streams, lakes, reservoirs, vagrant flood-waters, artificial channels, field irrigation or artificially spread flood-waters.

Absorption from rainfall and melting snow occurs from water-films or small pools, that from field irrigation and water spreading from thin sheets, while that from other sources is from stationary or moving bodies of surface-water of varying depth. For absorption to occur from the latter, it is necessary that the free water-surface be at a higher elevation than the adjacent water-table. In all cases it is necessary that the absorbing material have appreciable permeability as well as porosity.

Relation of capillarity to absorption--The physical process of absorption and penetration has been so little studied that reference to recent fundamental research is not out of order. In absorption by non-saturated material the phenomenon of liquid surfaces and capillarity are involved. Theory in this field has been revolutionized in recent years by the application of ideas regarding molecules as developed in organic chemistry. It has been demonstrated, for example, that curved liquid surfaces have different pressures on opposite sides [see reference (1)]. The concave air-water surface produced by the liquid-solid contact-angle of water when in a tube or between plates has a negative or upward pressure on the water side. The rise of water in capillary tubes is in response to this unbalanced negative hydrostatic pressure, and its amount is registered by the weight of the column of water drawn up into the tube.

Applying this concept to non-saturated soils, water moving downward in capillary films is acted upon by a force equal to the sum of gravity and capillary pressure, while if moving upward it is the difference that is operative. Horizontal movement, on the other hand, is actuated by capillary pressure alone.

In the case of unequal distribution of capillary moisture in non-saturated soil, movement is in response to the unequal concavity of the films at different points as produced by the differing thickness of the water-film. This unequal concavity produces unequal pressure upon the water within the films, which is equalized by flow from the region of thick films to that of thin. If the inequality in thickness of film is not maintained by inflow of additional water from a source of free water, movement will cease when pressures have been equalized within the volume where films are in continuous contact (2).

The investigations of Veihmeyer in California in connection with soil moisture as related to irrigation (3,4), and McLaughlin's laboratory studies of capillary movement of soil-moisture (5), confirm these theoretical deductions. Stated briefly, these investigators have found that capillary migration into dry soil continues only so long as there is a continuing source of free water in contact with the soil-column sufficient in quantity to maintain soil-moisture in the column at or above field capacity. [Field capacity is defined as the moisture-content of soil with unrestricted drainage and no decided discontinuities in types or structure, as observed 24 to 48 hours after water from rain or irrigation has disappeared from the surface and downward movement has practically ceased (39)]. This term was developed in soil-moisture investigations and is widely used among agricultural engineers. In view of the fact that the capacity of soil and rock to retain water against the pull of gravity for any con-

siderable length of time is considerably less than field capacity, its adoption as a hydrologic term is questionable, and its use in this report is tentative pending the availability of some more acceptable term.] Without such source, capillary migration is practically limited to the soil-body initially moistened, and consists of readjustments of moisture between areas of excess and deficiency with respect to field capacity. With moisture-content reaching an equilibrium at or less than field capacity and no contact with a body of free water, movement of soil-moisture is observable but is too slow to have any practical or economic significance.

These findings have a very practical bearing upon the problem of absorption for they indicate the importance of classifying the sources of absorption with reference to continuity. Permanent sources such as perennial streams, lakes, reservoirs, and main canals, are capable of maintaining constant moisture-conditions in the adjacent soil. This will differ for different soils and different conditions of the water-soil contact-surface, but will be at some point between the two limits of field capacity and saturation, and will extend down to the water-table. Intermittent sources, on the other hand, such as precipitation, intermittent or torrential streams, flood-waters, lateral irrigation-ditches, and field irrigation, permit of the drying out of the soil at more or less regular time-intervals, with the result that soil-moisture may at times drop considerably below field capacity at least throughout the zone occupied by roots. With the return of the supply, penetration cannot extend beyond the point to which moisture is restored to field capacity. If the depth to the water-table is great and the supply is out off before penetration reaches a region above the water-table where soil-moisture equals or exceeds field capacity, there can be no bridging over of the zone which is deficient in soil moisture and absorbed water cannot reach the water-table.

Absorption from precipitation--The differences between permanent and intermittent sources of absorption are fundamental and necessitate radical differentiation in methods of quantitative measurement. The use of a lysimeter for intercepting and measuring deep penetration from rainfall has advantages, but has thus far been largely unsuccessful especially in semi-arid regions, although experiments now being carried on by the United States Geological Survey in southwest Texas are giving encouraging results and are to be continued during the coming year. For intermittent sources such as precipitation in semi-arid regions with a distinct wet and dry season, a procedure is being developed in connection with rainfall penetration-studies by the United States Department of Agriculture, Bureau of Agricultural Engineering, in Southern California (6), and the United States Geological Survey in Central California (7) and by the United States Geological Survey on the outcrop of the Carrizo sandstone in the Winter Garden district of southwestern Texas (results unpublished), which gives great promise. Important features are the use of the improved sampling tube developed by Vaihneyer (8) and the determination of moisture-equivalent as a measure of field capacity. Vaihneyer has done much to standardize the moisture-equivalent determination (9), and has shown that it is a close measure of the field capacity of fine-textured soils although not always of sandy soils (10). It is to be noted, however, that tests on earthy materials other than soils have not been made. In the Southern California work it was found desirable to make samplings to a depth of 18 feet, and for gravelly and hardpan formations a compressed-air hammer to drive the soil-tube and a jack to withdraw it from the soil were developed (11,12).

The method consists of frequent soil-moisture determinations to a depth below the root zone at selected plots in areas of typical soils, vegetation, and surface treatment, coupled with measurements of rainfall, runoff, and depth of penetration. Where soil-moisture is below field capacity at the beginning of the rainy season, it has been found that the lower limit of penetration is marked by a sharp color line which can be determined from time to time by digging trenches. The computation of permanent absorption is accomplished by keeping a balanced inventory of rainfall and its disposal for the plot. As long as moisture-deficiency continues, there is no deep percolation and soil-evaporation and transpiration is the difference between rainfall and the sum of runoff plus soil-moisture added to storage. It has been found possible to artificially extend the period of soil-moisture deficiency by laying out two or three adjacent plots, sealing all but one, and holding others in reserve until moisture exceeds field capacity at the first one. Where very little rainfall is required to satisfy moisture-deficiency, this procedure is not practical and evaporation- and transpiration-losses must be estimated during a considerable portion of the rainy season.

If the rainy season occurs during the winter, such losses are small and no important error is introduced. For a summer rainy season the losses are large, and measurements must be made of soil-evaporation and transpiration.

It has also been found that for soils in which moisture at the beginning of the rainy season has been greatly depleted by evaporation and transpiration and approaches the wilting point, the amount of precipitation required to satisfy the deficiency may be so great that deep percolation will take place only during great storms occurring in seasons of abnormally large rainfall. On the other hand, for soils which because of irrigation, absence of vegetation or shallow water-table, the moisture-content exceeds field capacity except at very shallow depths, the moisture-deficiency will be overcome early in the rainy season of normal and even dry years, and all precipitation falling thereafter which is not disposed of as immediate runoff or subsequently lost by soil-evaporation or transpiration, penetrates deeply and is permanently absorbed.

The California investigations are still in progress and the results have so far proved very satisfactory. The method of soil-moisture determinations in southwestern Texas, however, has thus far not been very satisfactory, partly because of the relatively shallow depths of the unconsolidated materials overlying the Carrizo sandstone. Sonderegger has contributed a valuable discussion of methods for application of such data to large valley areas (31). This method is also applicable to measuring absorption from field irrigation and vagrant flood-waters. It is not ordinarily applicable, however, to measuring permanent absorption from precipitation in humid regions. For such areas the method by measurement of ground-water runoff, rise of the water-table, and soil-evaporation plus transpiration, is applicable as followed by Meinzer in the Pomperaug Basin, Connecticut (37).

Absorption from stream-channels--The measurement of absorption from intermittent sources covering limited areas such as stream-channels is a simple matter where accurate comparative discharge-measurements can be made or where the whole flow is absorbed. If the problem involves determining losses over a section of channel of an intermittent torrential stream, the difficulties are great, due to limitations in accuracy of stream discharge-measurement. Channel losses may be of the same order of magnitude as errors of measurement, so that the results of an expensive series of measurements might be indeterminate. The most notable instance of attainment of a high degree of accuracy in the measurement of a torrential stream for this purpose is that by the Engineering Department of the California State Water Commission in connection with studies on Niles Cone, Alameda Creek, California (13). Every possible source of error was investigated and extraordinary efforts made to reduce error to a known minimum. In Mimbres Valley, New Mexico, White was able to compute absorption from the Mimbres River because the stream, although normally torrential, disappears entirely or almost entirely in its course from the mountains to the floor of the valley (41).

A difficult problem arises in determining losses from a perennially flowing stream which is subject to large floods. This is well illustrated by the difficulties experienced by the United States Geological Survey on Mokelumne River, California, where the average annual runoff is about 800,000 acre-feet and the annual losses in a section of valley channel 32 miles in length are about 12,000 acre-feet or less than two per cent of the total flow of the river (14). The minimum limit of error for stream gaging work on natural streams is usually considered to be from two to five per cent. It is probable that in such instances a more accurate quantitative measure can be obtained by determining the difference between consumptive losses and rainfall absorption within the area for which water-table contours indicate that the stream contributes to ground-water.

A problem of absorption which has been the subject of much debate, but which has received little systematic study, is the effect upon the amount of absorption of differing flood-stage in torrential streams. Opposing views maintain, on the one hand, that it is the hydraulic pressure created by the flood-stage of the stream which is essential to maximum absorption and replenishment of ground-water, and, on the other, that it is the area of the wetted perimeter of the channel and the length of the contact-period which is important. The first holds that torrential flow and high flood-stage must be perpetuated in order that the adjacent landowners may secure continued enjoyment of the benefits of absorption from the stream, while the other contends that by

regulation of the flow, natural absorption can not only be maintained but greatly increased because of the prolongation of the contact-period without material reduction in wetted perimeter. The problem is one of vital importance on many western streams because of the dependence of valley landowners upon ground-water from wells to irrigate crops, and the growing need of storage regulation for reducing flood-hazard and for water-supply.

As is often the case in controversial matters, a detailed investigation of the physical facts shows there are other factors involved, and that the answer may ultimately be predicated upon a broader viewpoint. Investigational work has shown, for example, that in some cases geological conditions do not admit of stream-fluctuations affecting ground-water beyond the formations in immediate contact with the channel. Also that where the stream exerts a wider influence, soil-moisture conditions with respect to saturation have a profound influence. It has been found by tunneling and other methods of exploration under stream-channels that the material immediately beneath the stream-channel is not always saturated, and that the downward movement of absorbed water may be through capillary films. This condition has been found to exist beneath certain permanently flowing streams as well as those of intermittent flow. Preliminary experiments being made at Pacific Hydrologic Laboratory under the direction of Charles H. Lee (results unpublished), show conclusively that the variation in the rate of absorption by a soil-column under a head of water, although directly proportional to the head loss for saturated material in contact with free water at the effluent end (Darcy's Law), is more nearly of the order of the cube or fourth root for partially saturated soil freely draining at the effluent end. Application of the new concepts of capillary films apparently furnishes the explanation of these laboratory tests, namely, that a system of capillary films in a soil-column exerts a positive back pressure against a force tending to increase the film thickness such as hydraulic pressure. An illustration of the comparative situations represented by flow of water through saturated and unsaturated materials is that of air flowing through a system of connected rigid spheres with an outlet, and into a system of partially inflated rubber balloons.

Considering another phase, namely, a stream in contact with saturated material, intensive field research has shown that maximum rate of absorption at flood-stage occurs when the channel banks at initial stages of the flood have been drained to field capacity or less and have storage as well as transmission capacity. When the banks become saturated, a "back pressure" is exerted resulting from frictional resistance to percolation in the material (13). This condition greatly reduces the amount of absorption, and when the flood-stage recedes, drainage occurs with the return of much of this "bank storage" to the stream. It would thus appear that the full effect of head at flood-stage is not reflected in the amount of absorption for streams even when in contact with saturated material.

Absorption from lakes and reservoirs--Very little study has been given the absorption from permanent lakes and reservoirs. However, the subject is one of considerable economic importance and is of much concern to interests dependent upon such for water-supply. The conditions at Hayden Lake, Idaho, during the past few years, illustrate the extent to which absorption from a natural lake may deplete water-supply depended upon for irrigation. Many similar experiences have occurred with artificial reservoirs, in some instances necessitating abandonment. The subject is beginning to receive attention, some of the geological and ground-water aspects having recently been investigated by the United States Geological Survey (15, 16). The practical applications in forecasting probable leakage from proposed reservoirs and devising economically feasible methods of sealing large absorption-areas in reservoir-bottoms, are also being given attention (17).

Relation of watershed vegetation to absorption--A controversial subject upon which much research has been done recently or is now in progress is the relation of watershed vegetation to absorption and direct surface-runoff. This subject is closely connected with soil-erosion and the investigational projects include more or less of this phase. A complete bibliography was published in 1927, accompanying a reprint of an earlier report by Raphael Zon, which summarized the available data as of 1912 (18). Notable intensive investigations on small watersheds in the Rocky Mountains are represented by the work of Bates and Henry at Wagon Wheel Gap, Colorado, in comparing measured runoff during a series of years before and after forest denudation by fire

(19), and Porshing on the Wasatch Plateau in Utah upon the influence of range grasses upon absorption, surface-runoff, and soil-erosion (20). Lowdermilk has shown the great importance of vegetable matter on the ground to assist absorption of moisture by the soil (21). At the present time important general investigations are in progress at the Appalachian and California Forest experiment-stations of the United States Forest Service. The latter is especially complete, the following description having been furnished by Dr. W. C. Lowdermilk, a member of the Committee who is in immediate charge.

1. Effects of burning forest and chaparral vegetation on absorption and superficial runoff and soil-erosion. Experimental installations consist of 14 one-fortieth acre bordered plots in three localities, equipped with automatically recording instruments to measure intensity of rain storms and rate of runoff. Installations to be increased.
2. Role of litter from forest, chaparral, and grass vegetation on absorption, superficial runoff evaporation and erosion under artificially applied rain. Installations consist of 18 tanks, 10 and 20 square feet projectional area, each filled with 2-1/2 and 3 feet of soil.
3. Influence of chaparral (brush) vegetation on percolation, evaporation, transpiration, and superficial runoff from rain. Installations consist of 10 large lysimeters with surfaces sloping at 27-1/2 per cent, each with a projectional area of 80 square feet, and a soil-depth of 50 inches. Installation provides for manipulation of vegetation to determine effect on amount of percolation through the soil. In addition, small lysimeters are installed at the runoff installations to measure transpiration and evaporation from drained soils. These installations consist of 14 tanks with 3 feet of soil.

Other research work--This paper does not permit of more lengthy comment on current research work on absorption, but reference should not be omitted to the work of the Committee on Water Conservation, Irrigation Division, American Society of Civil Engineers, which under the direction of S. T. Harding, Professor of Irrigation, University of California, is preparing a summary on the subject of absorption from rainfall of all available material in English. This work should be extended to foreign literature, if, and when funds permit.

Kenneth Q. Volk, also a member of the Water Conservation Committee, is engaged in the preparation of a very comprehensive technical report on the subject of Water spreading as practiced in Southern California for the replenishment of ground-water by the artificial spreading of flood-waters from torrential streams. Valuable field tests of rates of absorption from spread flood-waters diverted from San Gabriel River near Los Angeles, California, are being conducted by the United States Department of Agriculture, Bureau of Agricultural Engineering. A preliminary report by A. T. Mitchelson gives results to date and a resumé of other similar research studies in the vicinity (22). Mitchelson has recently defined "water-spreading" as the diversion of water from natural streams onto and spreading it over adjacent land, thereby causing, it to spread over greater area, thus increasing percolation into the soil structure.

Transpiration and consumptive use

Transpiration is the process by which water-vapor leaves the living plant body and enters the air. It includes both stomatal transpiration consisting of the outward diffusion of already formed water-vapor through the pores of stomata and lenticles into the air, and cuticular transpiration or evaporation from moist membranes directly into the air. The former represents the most important part of the entire water-loss as cuticular transpiration does not exceed from 3 to 20 per cent of the total.

Transpiration is a process which is of particular interest to plant physiologists and ecologists, and a great wealth of scientific information is available as well as considerable research work in progress. Dr. B. E. Livingston, Laboratory of Plant Physiology, Johns Hopkins University, Baltimore, Maryland, and Prof. J. E. Weaver, Department of Botany, University of Nebraska, Lincoln, Nebraska, both members of this Committee, have been especially active. No attempt will be made in this report, however, to refer to such work except as it relates directly to the subject of hydrology.

The hydrologist is interested in transpiration primarily as a basis for quantitatively determining water-losses from vegetation. Such losses represent water absorbed by roots of plants either from the zone of saturation, the capillary fringe, or the belt of soil-water. The first two sources represent ground-water, and the last absorption from precipitation in storage or in transit to the water-table (water in excess of field capacity). From the standpoint of hydrology and its practical applications in engineering, forestry and agriculture, the ultimate objective is not the transpirational loss from the soil but total soil-losses. These include in addition to transpiration-loss, the evaporation occurring directly from the soil beneath and adjacent to individual plants, such moisture being derived either from the soil-belt, capillary fringe, or from the water-table, depending upon the depth of the latter. Because of this fact and the adaptability of observational methods to determining the sum of all soil-moisture losses, the term "consumptive use" has come into use among irrigation engineers as representing the sum of transpiration and soil-evaporation losses from cropped land.

Consumptive use--Consumptive use as recently defined by the Duty of Water Committee, Irrigation Division, American Society of Civil Engineers, is the quantity of water in acre-feet per cropped acre per year absorbed by the crop and transpired or used directly in the building of plant tissues, together with that evaporated from the crop-producing land (30). This definition, although limited to cultivated crops, can be applied equally well to natural vegetation as has been the general practice in recent literature (8).

The practical use of quantitative data for transpiration and soil-evaporation requires that it be reduced to terms of depth of water over unit area. It should also extend over a complete annual climatic cycle. Much of the quantitative work which has been done in transpiration is not adapted for use by the hydrologist, both because observations have been expressed in terms of weight of water required to produce a unit weight of dry matter and also have in many cases been limited to short periods of time. Consumptive-use data are thus of far greater value to the hydrologist than transpiration, except in the case of cultivated crops where the annual acre production of dry matter can be determined as in the case of alfalfa. It is to be noted also that consumptive use differs from the term duty of water so much used by irrigation engineers. The latter represents the depth of water per acre applied in irrigation upon the surface, and as reported seldom includes a statement of the amount of water drawn from capillary moisture either in storage or as currently supplied by rainfall during the growing season. In only rare instances can duty-of-water data be classed as consumptive use. The following review of investigational work will be confined to consumptive use, with inclusion of transpiration and duty-of-water data only where such can qualify under the definition.

There are two methods employed for determining consumptive use--the growing of vegetation in pots or in tanks sunk into the soil flush with the surface, and in field plots. In order to obtain reliable results by either method, certain conditions must be fulfilled (30). The requirements for dependable results with tanks are:

- (1) The quantity of soil used must be great enough to permit normal development of the plant and no interference with the processes of transpiration.
- (2) Atmospheric conditions surrounding the tank must be the same as in the field. (For a recent study of the relation of consumptive use of tules in isolated tanks and in tanks closely surrounded by a normal growth, see report by Lee on "Evaporation and transpiration in the Delta of the Sacramento and San Joaquin rivers, California" (38).
- (3) The plant-density must be the same as in the field.
- (4) The soil in the tanks must be in the same physical condition as in the field so as to have the same aeration and water-movement.

For field plots it is necessary that the water-table be at a depth too great for root penetration to the capillary fringe, and that there be a zone of soil below the depth of root penetration in which soil-moisture is less than field capacity. The latter requirement is the most difficult of attainment even with small applications of irrigation-water, and often introduces an element of uncertainty into the results from field plots.

There has been considerable recent work in measurement of consumptive use of individual varieties of crops and natural vegetation as well as evaporation from bare soil, and much of this work is now in progress. Notable progress has also been recently made in developing methods for determining consumptive use over large areas. Four methods for determining consumptive use for irrigated valleys as developed by Crandall, Hedke, Harding, and Meeker, have recently been described and discussed (30). A new method for determining the total evapo-transpiration loss from mountain drainage areas has been proposed by Lee (31). In Escalante Valley, Utah, in an area where alfalfa and a variety of desert plants derive their water-supply from water in the zone of saturation, White computed the consumptive use of the vegetation from daily fluctuation of the water-table (40).

Interception of precipitation

This subject, although closely related to the work of the Committee on Evaporation, is by agreement being included in the work of the Committee on Absorption and Transpiration. It is defined as the process by which precipitation is caught and held by foliage, twigs and branches of trees, shrubs, and other vegetation, and evaporated without reaching the ground. Work has recently been done by Planey in measuring the amount of interception from artificial rainfall by citrus trees (6). Contribution to the subject has also been made by Phillips (32).

Relations of absorption and ground-water discharge to ground-water levels and flow of streams and springs

This subject has thus far received very little attention by the Committee, and discussion of it will be deferred to a future report. In passing, it might be mentioned, however, that recently a very vital problem has arisen in connection with ground-water levels as indicated by wells penetrating stratified alluvial deposits. Such formations are among the most important sources of ground-water for economic use, and with the growth of population and occurrence of dry years, have been intensively developed, especially in the southwestern states. Wells are being sunk deeper and deeper, and improvements in pumping machinery now permit of economic extraction of water to maximum well-capacity. When systematic study of ground-water commenced in the United States about 30 years ago, most of the available wells were shallow dug or casing wells equipped with hand pump or windmill. Water-level in such wells usually represented the water-table, and except for temporary drawdown at the time of extracting water, truly reflected the fluctuations produced by additions to ground-water from absorption or extractions by natural discharge such as soil-evaporation, transpiration, and drainage into springs and streams.

Today the situation has changed. Most wells now penetrate confined strata containing water under more or less pressure, and water-levels do not so frequently represent water-table but rather pressure level, which latter may differ in elevation from that of the water-table by many feet. Furthermore, the installation of modern power-pumps now produces sudden large fluctuations in pressure level which quickly affect water-level in other wells penetrating the same formation. These pressure effects are registered in surrounding wells within a few seconds or minutes, and within a period of hours are sometimes noted at distances exceeding one mile. Water-level records obtained from wells penetrating such strata entirely fail to indicate the behavior of the water-table during the annual cycle, and in many cases may not indicate the elevation of water-table even at the end of the non-pumping season. The existence of these changed conditions, although of vital importance in the interpretation of well-fluctuation records, is not yet generally realized. The bearing which it may have upon ground-water field methods will be investigated by the Committee during the coming year as it is a matter of especial importance in studying the relation of absorption and water-table fluctuation.

Summary

This report, in its attempt to review the present status of progress in the fields of activity which have been assigned to the Committee on Absorption and Transpiration, incidentally brings into prominence some of the problems to which the Committee may well give its attention in the future. Among these may be mentioned the encouragement and coordination of study and research on the following:

- (1) The theoretical application of modern scientific concepts regarding surfaces and capillarity to the various phases of absorption.
- (2) Determination of the fundamental differences, if any, between gravity-flow through capillary films in a non-saturated soil with moisture-content exceeding field capacity, and in a saturated soil.
- (3) Determination of the relation of pressure head to stream-bed absorption by non-saturated materials.
- (4) The method for measuring rainfall absorption in semi-arid regions by soil-moisture determinations, and the standardization of methods for practical application of results obtained by this method to large areas over periods of years.
- (5) Standardized methods of measuring rainfall absorption in humid regions.
- (6) The determination of transpiration throughout the annual cycle, and also consumptive use, for various types of vegetation (especially those for which little or no data exists), under differing soil, water-supply and climatic conditions, and also the development of standardized methods for obtaining consumptive use for large areas.
- (7) The relation of vegetation to absorption of precipitation, total runoff, and low water stream-flow for mountain watersheds.
- (8) Interception of precipitation including both rain and snow.
- (9) The effect of modern deep-well development and power-pumping upon water-level observations in wells and its relation to selection and observation of record wells.

The Committee's work for the immediate future will include the preparation of a bibliography and list of workers in its special fields, standard definitions for much-used terms and concepts, and organization of its membership for specific activities along the lines indicated above and others which may be suggested. Communications from those who are interested in the work of the Committee would be welcomed by the Chairman.

References

- (1) Adam, N. K. The physical chemistry of surfaces. Oxford University Press, 1930, pp. 1-24.
- (2) Comber, Norman M. An introduction to the scientific study of the soil. Edward Arnold and Co., London, 1929, p. 1831.
- (3) Veihmeyer, F. J. 1927. Some factors affecting the irrigation requirements of deciduous orchards. *Hilgardia* 2:126-284.
- (4) Veihmeyer, F. J., and A. H. Hendrickson. The relation of soil-moisture to cultivation and plant growth. *Proc. Papers, First Internat. Cong. Soil Sci., Washington, D.C., 3:498-515, 1927.*
- (5) McLaughlin, W. W. Capillary movement of soil-moisture. U.S. Dept. of Agriculture, Bull. 835, 1920.
- (6) Blaney, H. F., C. A. Taylor, and A. A. Young. Rainfall penetration and consumptive use of water in Santa Ana River Valley and Coastal Plain. Bull. 33, Division of Water Resources, Dept. Public Works, State of California, 1930.
- (7) Stearns, H. T., T. W. Robinson, and G. H. Taylor. Geology and water resources of the Mokelumne Area. California Supplement to Water-Supply Paper 619, U.S. Geol. Sur. (manuscript), December 1930.
- (8) Veihmeyer, F. J. An improved soil-sampling tube. *Soil Sci.*, v. 37, No. 2, 1929.
- (9) Veihmeyer, F. J. Some factors affecting the moisture equivalent of soils. *Proc. Papers, First Internat. Cong. Soil Sci., 1927, v. 1.*
- (10) Veihmeyer, F. J., and A. H. Hendrickson. The moisture equivalent as a measure of the field capacity of soils. *Soil Sci.*, v. 32, No. 3, Sept. 1931.
- (11) Taylor, C. A., and H. F. Blaney. An efficient soil-tube jack. *Soil Sci.*, v. 27, No. 5, May 1929.
- (12) Soil sampling with a compressed air unit. *Soil Sci.*, v. 31, No. 1, Jan. 1931.
- (13) Final determination under agreement of September 1, 1916, between Alameda County Water District and Spring Valley Water Company, by California State Water Commission of 1916 dated Dec. 28, 1920, with supporting engineers' reports (manuscript). Dec. 1920.

- (14) Stearns, H. T., T. W. Robinson, and G. H. Taylor. Geology and water resources of Mokelumne River, California. Water-Supply Paper 619, U.S. Geol. Sur., 1930.
- (15) Meinzer, O. E. Relation of ground-water conditions to leakage of reservoirs. Trans. Amer. Inst. Mining and Metallurgical Eng., 1929.
- (16) Bryan, Kirk. Geology of reservoir and dam sites with a report on the Owyhee Irrigation Project, Oregon. Water-Supply Paper 597-A, U.S. Geol. Sur., 1929.
- (17) Lee, Charles H. Sealing Chenery Reservoir--Novel method uses bentonite suspension. Western Construction News, Dec. 25, 1930.
- (18) Zon, Raphael. Forests and water in the light of scientific investigation. Reprinted with revised bibliography 1927 from Appendix V of the Final Report of the National Waterways Commission 1912 (Senate Document No. 469, 62nd Congress, 2nd Session).
- (19) Bates, C. G., and A. J. Henry. Forest and stream-flow experiment at Wagon Wheel Gap, Colo. U.S. Mon. Weath. Rev. (Supplement No. 30), 1928.
- (20) Forshing, C. L. A study of the influence of herbaceous plant cover on surface-runoff and soil-erosion in relation to grazing on the Wasatch Plateau in Utah. Tech. Bull. No. 220, U.S. Dept. of Agriculture, 1931.
- (21) Lowdermilk, W. C. Further studies of factors affecting surficial runoff and erosion. Proc. Internat. Cong. Forestry Experiment-Station, Stockholm, 1929, pp. 606-626.
- (22) Mitchelson, A. T. Storage of water underground by spreading over absorptive areas. Bull. No. 32, Div. Water Resources, Dept. of Public Works, State of California.
- (23) Weaver, J. E., and John W. Crist. Direct measurement of water loss from vegetation without disturbing the normal structure of the soil. Ecology, April 1924.
- (24) Lee, Charles H. The determination of safe yield of underground reservoirs of the closed basin type. Trans. Am. Soc. Civ. Eng., v. 78, 1915.
- (25) Stearns, H. T., and L. L. Bryan. Preliminary report on the geology and water resources of the Mud Lake Basin, Idaho. Water-Supply Paper 560-D, U.S. Geol. Sur., 1925.
- (26) Stout, O. V. P. Cooperative irrigation investigations in the Sacramento-San Joaquin Delta, 1925 to 1930, Sacramento-San Joaquin Water Supervisor's Reports for years 1926 and 1930. Div. Water Resources, Dept. of Public Works, State of California (unpublished).
- (27) Widtsoe, John A. The production of dry matter with different quantities of irrigation water, and the yields of crop with different quantities of water. Utah Ag. Exp. Sta., Bull. 166 and 117, 1912.
- (28) Harris, F. S. The duty of water in Cache Valley, Utah. Utah Ag. Exp. Sta., Bull. No. 173, 1920.
- (29) Lewis, M. R. Experiments on the proper time and amount of irrigation, Twin Falls Exp. Sta. 1919.
- (30) Consumptive use of water in irrigation--Progress-report of duty of Water Committee, Irrigation Division, Am. Soc. Civ. Eng., with discussion. Trans. v. 94, 1930.
- (31) Sonderegger, A. L. Water supply from rainfall on valley floors, with discussion. Trans. Am. Soc. Civ. Eng., v. 94, 1930, p. 1242.
- (32) Phillips, I. P. Rainfall interception by plants. Nature, London, 1926.
- (33) Beckett, S. H., F. H. Blaney, and C. A. Taylor. Irrigation water requirement studies of citrus and avocado trees in San Diego County, California, 1926 and 1927. Bull. 489, Univ. Calif. Agr. Exp. Sta., 1930.
- (34) Huberty, M. R. Studies of the irrigation requirements of Sacramento Valley Lands, 1924-1928. Unpublished manuscript.
- (35) Sleight, R. B. Evaporation from the surface of water and river-bed materials. J. Agr. Res., v. 10, No. 5, July 1917.
- (36) Lee, Charles H. Discussion of paper, Evaporation on United States reclamation projects, by Ivan E. Houk, Trans. Am. Soc. Civ. Eng., v. 90, p. 266, June 1927.
- (37) Meinzer, O. E. A study of ground-water in the Pomperaug Basin, Connecticut. Water-Supply Paper 597-B, U.S. Geol. Sur., 1929.
- (38) Lee, Charles H. Evaporation and transpiration with special reference to a salt-water barrier below confluence of Sacramento and San Joaquin rivers. Appendix C, Bull. 28, Div. Water Resources, Dept. Public Works, State of California, 1931.
- (39) Hendrickson, A. H., and F. J. Veihmeyer. Irrigation experiments with peaches in California. Bull. 479, Univ. Calif. Agr. Exp. Sta., 1929.
- (40) White, Walter N. A method of estimating ground-water supplies based on discharge by plants and evaporation from soil. Water-Supply Paper 659-A, U.S. Geol. Sur. (in press).

- (41) White, Walter H. Preliminary report on the ground-water supply of Mimbres Valley, New Mexico. Water-Supply Paper 637-B, U.S. Geol. Sur., 1931.

58 Sutter Street,
San Francisco, California, April 1, 1932

ON RUNOFF

L. K. Sherman, Chairman

Members of the Committee on Runoff were appointed last fall. The Committee since that time has been active in formulating plans of organization and procedure. Based upon correspondence with the members, the Committee organization has been divided into four sub-committees, as follows: (1) On Rainfall, Chairman, C. S. Jarvis, Washington; (2) On Runoff Percentage, Chairman, W. W. Horner, St. Louis; (3) Rainfall Hydrographs of Runoff, Chairman, L. K. Sherman, Chicago; (4) Bibliography of Runoff and Data Re Research Agencies, Chairman, John C. Prior, Columbus, Ohio.

The Chairman of the Sub-committee on Rainfall has been engaged during the past year on important hydrologic investigations in connection with the Delaware Survey Report (H.D. 308). He advises that this forthcoming report contains certain ideas of generalizing physical phenomena and their limits, with reference to periodicity of recurrence in a given locality, together with sufficient correlated data to warrant his conclusions.

The Chairman of the Committee on Percentage of Runoff is preparing to report on personal investigations, and he is also in correspondence with members of other committees engaged in similar lines of work.

The Chairman of the Committee on Hydrographs of Runoff has published a paper in the Engineering News-Record of April 7 entitled "Runoff from rainfall by unit graph method." Copies of this paper were sent to all members of the Committee on Runoff, and the writer is gratified to note that published discussion will appear.

The Sub-committee on Bibliography feels that it has an important work on hand, and that possibly this should be an agency of the Section, rather than an agency of the Committee on Runoff.

Mr. Sherman has presented to the Committee a preliminary index and Bibliography of Rainfall and Runoff, with the idea that it may be used as a basis for further extension. Forty mimeographed copies have been made, and partly distributed. Some copies are available to other members of the Section of Hydrology who may be interested.

The field of the Committee on Runoff necessarily includes a number of subjects covered in more detail by special committees. It is felt, however, that no overlapping will occur, and the Committee on Runoff solicits the cooperation of members of the special committees.

1444 First National Bank Building,
Chicago, Illinois

ON UNDERGROUND WATER

David G. Thompson, Chairman

Scope of field covered by the Committee

A statement by Dr. O. E. Meinzer relating to the formation of the Section of Hydrology, presented at the first meeting of the Section in May, 1930, contained a list of 26 suggested fields of hydrology which might be covered by permanent committees. Half of the subjects mentioned in that list are more or less directly related to the hydrology of underground waters. Subsequently, the total number of committees actually organized was nine, and the number of those which in any way relate to underground

water was reduced to four. The work of three of these committees, namely, the Committee on the Physics of Soil-Moisture, the Committee on the Chemistry of Natural Waters, and the Committee on Absorption and Transpiration, also cover subjects that are not directly related to underground water. A large part of the subject-matter of the other fields relating to water beneath the Earth's surface that were originally suggested has been assigned to the Committee on Underground Water. There is, however, some overlapping in the fields covered by the four committees mentioned and a more definite division of the work will need to be reached by mutual discussion during the coming year.

Problems of ground-water hydrology might be divided into groups according to several different schemes. Lacking any adequate outline of these problems and lacking an opportunity to prepare such an outline, in this first report of the Committee on Underground Water there may be listed some of the principal phases of ground-water hydrology that may be considered to come within the scope of the work of the Committee.

- (a) Movement of water in the zone of saturation, including hydraulics of wells
- (b) Hydrology of artesian basins
- (c) Hydrology of non-artesian basins
- (d) Hydrology of limestone terranes
- (e) Hydrology of hot springs and volcanic terranes
- (f) Laboratory work in ground-water hydrology
- (g) Relation of fresh ground-waters to highly mineralized, especially salty waters
- (h) Hydrologic problems involved in studies of metalliferous deposits
- (i) Hydrologic problems involved in studies of petroleum deposits
- (j) Quantitative methods in ground-water hydrology
- (k) Hydrologic problems arising in the economic development of ground-water
- (l) Geologic conditions affecting the occurrence of ground-water
- (m) Drainage problems involving ground-water conditions
- (n) Ground-water hydrology of dams and reservoir sites

Obviously there is considerable overlapping in this list. Furthermore, the list should not be considered to be complete. It is given primarily to show the variety of subjects that may be considered by the Committee on Underground Water. In view of the diversity of subjects constituting the subject-matter of ground-water hydrology, in making up the personnel of the Committee an effort has been made to have every phase of the subject covered by men who have given special attention to the respective fields of investigation. When the work of the Committee is better organized it may be desirable to organize several sub-committees, or at least to assign certain phases of the field to one or more men for special attention.

In passing it may be pointed out that the terms underground water and ground-water have been used synonymously in the United States to designate water in the zone of saturation, although for some years many geologists and engineers have given preference to the shorter term. The term underground water has been used in the Committee name to conform with the usage of the International Committee on Underground Water which is a part of the International Union of Geodesy and Geophysics. The shorter term is quite convenient and its use may well be continued for general purposes.

Recent and current investigations of ground-water hydrology

The personnel of the Committee on Underground Water was not finally determined until late in February. The period intervening before the present meeting has been short, members of the Committee have been widely scattered, and it has not been possible to do much work. There has been no meeting of the Committee. The Chairman sent a letter to each member asking that he send in a statement of his own recent work on ground-water hydrology or that of others with which he may be acquainted, and also suggestions for desirable activities of the Committee. On the basis of the replies, and of his own knowledge of investigations of other persons he has prepared the following statement. If the statement appears to place undue emphasis on some investigations, it may be attributed to the fact that, lacking opportunity to make a more complete survey of the field, the writer perhaps has unduly but unintentionally stressed investigations with which he was familiar. Inasmuch as the present report is the first one of this Committee it is deemed proper to not confine the statement to work of the past year, but to record outstanding investigations within the past two or

three years. In order that the next report of the Committee may more adequately cover the field it is requested that any person who is making special ground-water studies communicate the nature of such studies to the Chairman or other members of the Committee. Suggestions for desirable future activities, requests for information as to investigations by others, etc., also will be welcome.

In addition to brief statements furnished by several members of the Committee, three of them have prepared more formal statements. These statements are one on "Hydrological investigative work by petroleum companies" by Parker D. Trask; one on the closely related subject of "Problems of underground water-flow in the oil industry" by Dr. Morris Muskat; and one on "Investigations of underground-water problems in Arizona, California, New Mexico, and Oregon" by A. M. Piper. The papers by Messrs. Trask and Piper are appended to this report, and that by Dr. Muskat, which was presented formally at the meeting of the Section, is printed in the Transactions.

Probably the most extensive investigations relating to the hydrology of underground waters are being carried on by the Division of Ground-Water of the United States Geological Survey. The work of the Geological Survey involves not merely the collection of statistical facts in regard to occurrence of ground-water but also a study of the fundamental principles that govern the occurrence and movement of the water which must be understood if the best economic use is to be made of this valuable resource of mankind.

The present activities of the Division of Ground-Water of the Geological Survey comprise approximately 40 separate projects in various stages of progress. Most of these relate to investigations in specific areas, but several relate to general problems. Furthermore, a large percentage of the areal investigations relate to the quantity of water that can be withdrawn without depleting the supply. The areal investigations are being made very largely in cooperation with States, counties, cities, or other governmental units on a basis of the Federal expenditure being limited to not more than 50 per cent of the total cost. By this arrangement the States and other local governments receive the benefit of investigations that require a knowledge of specialized information in a field in which the experienced personnel is rather limited. The demand for investigations on a cooperative basis has been so great that funds have not been available for the study of fundamental problems that are recognized to be necessary if progress is to be made in increasing the value of many of the areal studies in regions where ground-water has a high actual or potential value. In the present brief report it is possible only to mention certain phases of the investigations of the Geological Survey in so far as they relate to fundamental principles of ground-water hydrology.

A valuable contribution to the general subject is a paper by Dr. O. E. Meinzer entitled "History and development of ground-water hydrology," which was presented at the presidential address before the Geological Society of Washington on December 9, 1931. In this paper Dr. Meinzer presents and discusses the early theories as to the origin and occurrence of ground-water and the gradual modification and development of the early theories into their present state.

Another contribution by Dr. Meinzer, a paper on "Methods of estimating ground-water supplies," has just been published as Water-Supply Paper 638-c. This is the first of a symposium of three papers originally presented in abstract form at a meeting of the Geological Society of America in 1928, but now revised and enlarged. A second paper of the series, "A method of estimating ground-water supplies based on discharge by plants and evaporation from soil, Results of investigations in Escalante Valley, Utah," by Walter N. White, is now in press as Water-Supply Paper 659-a. The third paper, "Methods of estimating ground-water supplies in artesian basins," by David G. Thompson, is being brought to completion. More or less intensive investigations by the Federal Survey, in cooperation with State or other governmental agencies, in regard to the quantity of ground-water available for domestic, industrial, and irrigation use, based on methods described in the three papers mentioned, are now in progress in New York, New Jersey, Florida, Arkansas, Nebraska, Texas, New Mexico, Utah, Idaho, Oregon, and California. In this connection there should also be mentioned extensive experimental work done by Leland K. Wenzel in regard to Slichter's electrical method and the so-called Thiem's method of determining the permeability of water-bearing beds. The test of Thiem's method, which was carried on in cooperation

with the Nebraska Department of Conservation and Development, is described in a paper by Mr. Wenzel, published in the Transactions of the Section of Hydrology. In connection with his investigations Mr. Wenzel has also given consideration to the theoretical mathematics of the motion of underground waters, as has also C. V. Theis in connection with his studies of ground-water conditions in Portales Valley, New Mexico. (See paper by Mr. Theis published in the Transactions.)

The widespread drought of 1930 created much interest, especially among those interested in the production of hydro-electric power, in the relation between ground-water conditions and stream-flow. In this connection Dr. Meinzer presented a paper on "Relation of ground-water to stream-flow" before the Hydraulic Power Section of the National Electric Light Association in October, 1931. Other investigations relating to this subject are described in papers by S. W. Lohman and R. C. Cady, published in these Transactions.

A study in regard to so-called ebbing and flowing or periodic springs has been in progress for some years by Dr. Meinzer and others. Continuous records obtained by automatic recorders are available for one spring in Virginia for several years, and for other springs in Virginia and Wyoming for shorter periods. Incidentally, fluctuations in the flow of several other large springs in different parts of the country are now being accurately determined by the Division of Surface-Water of the Geological Survey.

For some time it has been realized that long-time records of the fluctuation of the ground-water table, and of the piezometric surface in artesian basins are needed to more clearly solve important ground-water problems, but such records are scarce. In southern California the Geological Survey has made periodic observations of the water-level in a considerable number of wells for nearly 30 years and these are being continued. Observations for considerable periods have also been made in other localities in California, especially in connection with investigations of the State Division of Water Rights and other State organizations.

Although doubtless records of the fluctuation of the ground-water level have been kept for long periods in other regions, few good records are known to the writer. In 1923 the Geological Survey, in cooperation with the New Jersey Department of Conservation and Development, under the direction of the writer, began periodic observations in several regions in New Jersey and these are being continued in cooperation with the State Water Policy Commission, to which has been transferred the functions of the Department of Conservation and Development relating to water supply, the work being under the direction of H. C. Barksdale. Practically continuous records for a period of 6 to 8-1/2 years have been obtained by automatic water-level recorders on several wells, and for shorter periods on about 25 wells, in six widely separated regions of the State where continuing investigations are in progress to determine the effect of probable future increases in consumption of ground-water. So far as the writer knows, these observations are the longest carefully made records in the humid eastern part of the country. The records have revealed many interesting facts, but only a single important observation relating to conditions on a deep water-bearing sand--the so-called 800-foot sand at Atlantic City--may be cited. The early records showed a considerable fluctuation in the head on the formation from winter to summer which results from considerable changes in pumpage from the formation, but until 1929 in successive summers the head dropped to lower and lower levels, and each following winter it failed to rise as high as in the previous winter. In 1930 and 1931, however, in spite of an increasing deficiency in precipitation, the head has risen to successively higher levels in comparison to the same date in the previous year. The only plausible explanation for this behavior appears to be that, because of the depressed economic conditions, the consumption of water has decreased considerably. To this extent the observations verify a theory, hitherto unproven, that in this locality the head fluctuates primarily in response to fluctuations in pumpage, and that the previous more or less progressive decline in head did not necessarily indicate that the safe yield of the formation had been exceeded, nor was it due to a deficiency in precipitation.

Since the observations were begun in New Jersey similar observations on fluctuations in head have been made in connection with almost every areal investigation by the Geological Survey, and for some areas several years' records are now available. Notable among these may be mentioned the following: A study of the relation between

the fluctuations of artesian head on certain important water-bearing formations at Memphis, Tennessee, the stage of the Mississippi River, the pumpage from the formations, and the precipitation, is given in a paper entitled "A preliminary report on the artesian water supply of Memphis, Tennessee," by Francis G. Wells, published as Water-Supply Paper 638-a, and a more detailed discussion of the results is contained in a more extensive report on ground-water supplies of western Tennessee, now in press. The results show the water-bearing formations at Memphis to be unusually prolific and it is concluded a large additional quantity of water can be developed. An extensive study by D. G. Thompson to determine the safe yield of Pleistocene water-bearing beds for rice irrigation in the Grand Prairie region, Arkansas, based largely on a study of the relation between fluctuations of pumpage and water-levels, is described in a mimeographed statement released in January, 1931. This study is of interest because it describes conditions in a region where so much water has been withdrawn that part of the formation has been drained and water-table conditions exist where originally the water was under artesian pressure.

Observations on the water-levels have constituted a significant part of investigations in several parts of Texas under the general direction of W. N. White, as follows: In the Winter Garden area, by T. W. Robinson, S. F. Turner, A. N. Sayre, and J. H. Lonsdale; in the Houston area by S. F. Turner and P. P. Livingston; in the Glen Rose area by A. G. Fiedler; and in the Toyah Basin in western Texas by Hoyt S. Gale and S. S. Nye. In Florida observations by V. T. Stringfield on fluctuations of the water-table are being made not merely to determine the effects of pumping and of recharge from precipitation, but also to determine the effects of pouring large quantities of surface runoff and sewage into drainage wells in an area where the natural drainage is poorly developed. Observations on fluctuations of the water-level in wells and of the artesian pressure of flowing wells have also been used to good advantage in studies in the Roswell artesian basin in New Mexico, by A. G. Fiedler and S. S. Nye; in the Mimbres Valley area by W. N. White, published as Water-Supply Paper 637-B; in areas in Oregon under investigation by A. M. Piper and T. W. Robinson; and in the Mokelumne area in California under the general direction of Mr. Piper. In an investigation of the ground-water supplies of the Jordan River or Salt Lake Valley, Utah, in cooperation with the City of Salt Lake, R. M. Leggett and G. H. Taylor are making observations on the fluctuations of head and yield of flowing wells not only to determine the effects of recharge and discharge from various sources, but also in an endeavor to obtain information as to the probable geologic structure of the water-bearing beds. In this region considerable variation in the distribution of the water-bearing beds is to be expected but there are practically no reliable well logs and it is hoped that the observations will show whether or not the beds are interconnected.

Problems arising from the relation between fresh and salt ground-water are being investigated by the Geological Survey in cooperation with State or other local agencies in New York, New Jersey, Florida, Texas, Utah, and Honolulu. In New Jersey for several years periodic samples from several key wells close to the ocean have been tested for chloride. These wells draw from the 800-foot sand in the Atlantic City region, in which the head is now from a few feet to 75 feet or more below sea-level. Certain slight changes in chloride-content--only a few parts per million--but changes that are nevertheless definite, have been observed; but the reason for them has not been determined. On the other hand, during the past year there has been opportunity to observe the progressive salting of wells drawing from shallow water-bearing beds in the Atlantic City region from the time they were put into service until the time when the chloride-content became so great it became necessary to discontinue using them. In the Sarasota region, in Florida, in an area of several miles inland from the coast where there is considerable use of water from flowing wells for irrigation, Mr. Stringfield has found ground-water high in chloride with a lower chloride-content nearer the coast. Presumably the reduction in head, resulting from the withdrawal of water, has permitted salt-water to rise up from beneath the fresh-water layer, instead of moving in laterally from the Gulf of Mexico. In St. Petersburg, Florida, following the abandonment of the old public supply, which had been contaminated by salt-water, observations have been made on the freshening of the water in the contaminated aquifers.

Salt-water problems have been encountered in several areas in Texas. In the Winter Garden area the danger of contamination of fresh-water aquifers by leakage of salt-water from other aquifers through uncased wells and wells equipped with defective

casing has been investigated by Fiedler, Livingston, and Lynch. In that work the concentration of water at different depths in wells was determined approximately by an electrical method and thereby the location of the points of salt-water leakage were established. In the Houston region the problems of contamination of fresh water-bearing aquifers by salt-water is complicated by the presence of numerous salt-domes. In the investigation of the Jordan River Valley, Utah, by Leggette and Taylor, a study is being made of the relation between the fresh ground-water and the salt-water of areas bordering the Great Salt Lake. In connection with a study of the quantity of ground-water available for the City of Honolulu, by H. T. Stearns and K. N. Vaksvik, considerable attention has been given to the relation between fresh- and salt-water. This investigation also relates to the occurrence of ground-water in volcanic terranes.

The hydrology of limestone terranes has been considered in a report by W. D. Johnston, Jr., in a cooperative report on ground-waters of the Paleozoic region of Alabama, which is now being printed by the Alabama Geological Survey; in a report by A. M. Piper on the ground-water supplies of central Tennessee, which is now in press; in one on the ground-water supplies of south-central Tennessee, by C. V. Theis; in the investigations in Florida by Stringfield, already referred to; and in the Roswell artesian area, New Mexico, by Fiedler and Nye in a report which is now about to go to press. The work in all these areas is of especial interest in connection with the paper by Prof. W. M. Davis on The origin of limestone caverns, which was published in the Bulletin of the Geological Society of America in September, 1930, and in which the significant question is raised as to whether the solution of caverns in limestone occurs only above and a short distance below the water-table, or also at a considerable depth below it. In certain areas in Florida there is well substantiated evidence of large openings or crevices--presumably solution channels--at a depth of 600 to 800 feet, and perhaps more, below sea-level. The question of the relative position of the water-table when these channels were formed, is as yet unsolved.

In the hydrologic laboratory of the Geological Survey, in charge of V. C. Fishel, routine determinations have been made of the mechanical analysis, porosity, coefficient of permeability, and moisture-equivalent of unconsolidated samples of water-bearing materials, and some attention has been given to improving methods. An additional step has been to undertake the determination of the coefficient of permeability of cores of consolidated or partly consolidated samples of material.

Investigations by other Government and State bureaus are largely confined to the western States. Some of these are described in a paper by A. M. Piper, published in these Transactions of the Section, and others are described briefly below.

Several investigations relating to the drainage of land by means of pumping of wells have been in progress. Some of the results of one of these, carried on as a cooperative investigation of the United States Bureau of Agricultural Engineering and Oregon State Agricultural Experiment-Station, were published in the March, 1931, issue of the American Society of Civil Engineers, under the title of "Flow of ground-water as applied to drainage wells," by M. R. Lewis. A study of the effect of pumping from wells for both irrigation and drainage is being carried on by the Department of Agricultural Engineering of the University of Idaho, represented by Mr. Hobart Deressford, in cooperation with the Division of Irrigation, United States Bureau of Agricultural Engineering, represented by Mr. J. C. Marr. In this investigation a large number of measurements of drawdowns have been made and records kept of the quantity of water pumped from wells. Another investigation relating to drainage is described in a paper "The drainage of land overlying artesian basins," by Willard Gardner, Utah State Agricultural College, and O. W. Israelsen and W. W. McLaughlin, both of the United States Bureau of Agricultural Engineering. Dr. Gardner reports that he and others are engaged in further work on this subject, including the design for a multiple-intake well, consisting of a battery of small wells in circular arrangement leading to a central pump. A study is also being made under his direction of the hydrologic principles involved in the water-logging of land and its control.

Problems of ground-water hydrology relating to the possible drainage to lands caused by raising the water-level in a storage reservoir on the Kootenai River, Idaho, near the Canadian boundary, have been studied by T. R. Newell, United States Geological Survey, and L. T. Jessup, United States Bureau of Agricultural Engineering.

Prof. William Peterson, Director of Extension Division of Utah State Agricultural College, for some years has collected information on developments of ground-water and measurements of static head in the principal agricultural areas in the State and is preparing this information for publication.

Prof. Gordon M. Fair reports that the Department of Sanitary Engineering of Harvard University for the past two years has carried on a restudy of the flow characteristics of water through sand, based on a new evaluation of the size, surface, and volume-properties of sands. He states that although the study is not complete it promises to yield a rational formula for the flow of water through sand.

Dr. H. J. Fraser at Harvard University has recently completed a comprehensive report on "An experimental study of the porosity and permeability of elastic sediments." This investigation was briefly described in a paper by A. M. Piper at the 1931 meeting of the Section of Hydrology.

In connection with studies of metalliferous deposits in the Grass Valley, California, mining district for the United States Geological Survey, W. D. Johnston, Jr., undertook a study of relation between precipitation and pumpage of water from the North Star mine to determine the lag or rate of penetration of precipitation, and the storage of precipitation as underground water. He states that the results were unsatisfactory because of incomplete records on pumpage of water. Mr. Johnston is also engaged on a compilation of data relating to the exhaustion of ground-water storage as mines are developed. Along a somewhat related line has been the study during several years by R. D. Leitch, for the United States Bureau of Mines, on the contamination of streams in Pennsylvania by the acid water drained from working and abandoned coal mines. Although this study relates largely to the chemistry of natural waters Mr. Leitch's published reports contain information in regard to the quantities of water involved.

During the past year C. S. Jarvis, U. S. Army Engineer, has made a study to determine the possible damage to the Runyon well field of the Perth Amboy, New Jersey, Water Department, if the proposed Delaware-Raritan ship canal were dug across the well field. The damage might result not only from cutting off part of the surface drainage naturally tributary to the well field, but also from contamination of salt-water backing up the canal from Raritan Bay. Mr. Jarvis has also considered the effect of the canal on ground-water conditions elsewhere along the proposed route.

In connection with a project to develop a new water-supply free from salt-water contamination for St. Petersburg, Florida, Malcolm Pirnie has given considerable attention to the salt-water problem, and eventually selected a site for a well field some 30 miles north of the city where it is believed there will be little danger of contamination.

In connection with the work of the Water Conservation Committee, Irrigation Division, American Society of Civil Engineers, Charles E. Lee has prepared a paper on "Hydraulic permeability of earth--its measurement and relation to water conservation." The paper has been submitted for publication in the transactions of that Society.

A. L. Lugin, of the Nebraska Department of Conservation and Development, is engaged on an investigation of ground-water conditions in the area between the Platte and Republican rivers, in Nebraska.

Desirable lines of investigation

One of the objects of the Section of Hydrology is to promote research along fundamental lines. In following out this object suggestions have been solicited in regard to investigations that may be considered to be desirable. A list of these subjects is given herewith.

M. E. Lewis has suggested for consideration a study of the possibilities of legal control of the use of ground-water for irrigation. The subject of legal control of ground-water supplies is one that deserves careful study, but it is also recognized that difficult problems will be encountered. The problem is suggested for consideration of the Committee on Underground Water.

Prof. S. T. Harding, University of California, suggests a study of rates of draft and pumping effects in ground-water basins in order to arrive at a ratio between the total area of irrigable land and the area that can be irrigated from the ground-water reservoir without ultimate depletion of the supply.

W. C. Lowdermilk, California Forest Experiment-Station, Berkeley, California, suggests an investigation of the effect of recent faulting in draining bodies of ground-water that underlie uplifted erosion-surfaces.

A. M. Piper states that the work on the Mokelumne cooperative project indicates the need of a simplified and adequate technique for determining rainfall-penetration, soil-evaporation, consumptive use by vegetation, and specific yield of water-bearing materials.

Future work of Committee

There appear to be a number of ways in which the Committee on Underground Water can perform useful service in promoting our knowledge of this important branch of scientific study. Obviously, any very worth-while accomplishments can result only through more or less expenditure of time and money. Unfortunately, in these times of financial uncertainty, the item of expense, so far as the Section of Hydrology is concerned, is a stumbling block to the progress of the Committee's work. In spite of these handicaps it may be well to set up certain objectives toward which to head as rapidly as circumstances will permit, and some of these may be mentioned here.

The Section of Hydrology is affiliated with the International Association of Scientific Hydrology through the International Union of Geodesy and Geophysics. In connection with the next meeting of the International Association, which was originally planned to meet at Lisbon in 1933, there has been set up a plan for several so-called questions or reports on different phases of hydrology to be submitted by the national member organizations. Relating to the work of the Committee on Underground Water is the subject, quoting the words of the question, Artesianism (which may be translated freely as the hydrology of artesian waters): The definition, importance of artesian wells in the country, especially for deserts; means of exploitation and notably of the regulation of the flow of artesian wells. The Chairman of the Section has asked the Chairman of the Committee on Underground Water to prepare a report that will cover this subject.

In order that contact may be made with all persons actively engaged in ground-water investigations in the country an obvious need is an adequate mailing list of these persons and it is believed the compilation of such a list should constitute one of the first activities of the Committee.

For several years abstracts of most current articles relating to ground-water hydrology have been published in the Journal of the American Water Works Association or the Annotated Bibliography of Economic Geology. It is believed that these abstracts, together with abstracts in lesser number published in other technical magazines, such as Transactions of the American Society of Civil Engineers, Engineering News-Record, and Water and Water Engineering (London) sufficiently cover the field at the present time, and that no general project of covering the ground-water literature need be undertaken. However, if it appears that these magazines are not generally available to workers in the field it may be desirable to compile a short list of the more important articles published from time to time. Furthermore, in view of the fact that the fundamental source materials of ground-water hydrology are not available in any single treatise or series of reports, it may be desirable to prepare a selected list of references to the principal books and reports that cover different phases of the subject.

U. S. Geological Survey,
Washington, D. C., April 28, 1932

HYDROLOGICAL INVESTIGATIVE WORK BY PETROLEUM COMPANIES

Parker D. Trask

Last summer as the writer was about to depart for a trip of inspection of several oil districts of the United States, Dr. Meinzer suggested that he might inquire from oil men as to the extent that petroleum companies are investigating hydrological questions. It was not practicable for him to make a detailed study of the problem, but he obtained certain information which may be of interest to the Committee.

Water affects the exploitation of petroleum in a number of ways. The following are some of the problems with which petroleum technologists are confronted: (1) Encroachment of edge-water as petroleum is removed from an oil pool; (2) zones of water through which wells have to be drilled to reach underlying oil zones; (3) migration of oil from the sediment in which it originates to the place where it accumulates; (4) artificial flooding of oil zones with water in order to increase the production of petroleum; (5) the distribution of ground-water with respect to subsurface geologic structure as an aid in the finding of new oil fields; (6) water-supply for drilling the wells and for the people operating the oil fields; (7) separation of emulsions of water and oil; (8) disposal of the water produced with the oil; and (9) exploitation of oil-field brines.

Petroleum engineers are much concerned with the manner by which edge-water encroaches as petroleum is removed from an oil pool. Oil, being lighter than water, floats on a zone of underlying water (except in a few regions in which no ground-water is present). This underlying water exerts a certain hydrostatic pressure on the oil and this pressure facilitates the removal of the oil from the well. At the present time many of the oil companies measure this pressure and try to maintain it as long as possible in order to increase the life of the wells.

The rate of encroachment is a vital problem in the exploitation of each oil field and the petroleum engineers of oil companies give much attention to this problem for every field operated by their company.

In some regions, like the Bradford area of Pennsylvania, the field is flooded artificially with water. Wells are drilled at intervals; water is forced down into them under pressure; and as the water migrates through the sand, it forces oil into producing wells with the result that the yield of oil is increased.

For the successful operation of such flooding it is necessary for the petroleum technologist to understand the problem of migration of oil and water through sediments. The question of permeability is of great importance. Recently C. M. Nevin has written an article describing a method of measuring the rate of flow of fluids through rocks by means of measuring the time it takes a known volume of air under known pressure to pass through a known volume of sediment. Sediment impregnated with oil is first extracted with carbon tetrachloride to remove the oily substances.

Zones of water commonly overlie oil horizons. Knowledge of the position and character of these water-zones is essential to the proper exploitation of the oil wells. Not only does the water cause difficulty during the drilling of wells, but after wells begin to produce oil, leakages into the wells cause mixtures of oil and water. When water begins to be produced with oil, it is essential for the operators of the well to know the source of the water, whether from the bottom of the well, or from some place above the oil sand. The different zones of water which the well penetrates, generally have different chemical compositions. Most of the oil companies collect samples of the water and by means of a chemical analysis attempt to locate the source of ingress of water. In California, the Union Oil Company determines the position of the water by measuring the electrical resistance of the fluid in the well.

The problem of locating the source of water leaking into wells is the chief hydrological investigation now being carried on by most of the oil companies.

A few years ago attempts were made to determine the subsurface geologic structure by means of the distribution of salts in different zones of ground-water. Contours were drawn on lines of equal chemical content of the water, but the association

between the distribution of salts and the geologic structure was not sufficiently good for the oil companies to continue to attempt to use water-analyses for correlation of strata. Consequently, at present very little of such work is being done.

In some areas it is necessary for the companies to develop satisfactory water-supplies for operating their oil fields. This is especially true of areas in the southwest. However, such problems are generally of a local nature and when encountered have to be solved by the oil company's chemists and geologists. Some work has been done by a number of companies to inhibit the production of scale by hard water in boilers and in water pipes, but the writer has no details of such work.

The separation of emulsions of oil and water is a problem that concerns petroleum engineers, but the writer did not learn of any research work now in progress on that problem.

The disposal of the water produced along with oil, causes difficulty in some regions. Salt-water, if poured into streams, may contaminate the water so that it is not fit to drink. If the area is level the impounding of the water in basins may offer difficulties. In some regions it is practicable to put the water into abandoned oil wells, but this may contaminate the producing sand, with the result that the total recovery of oil from the pool is diminished.

The Texas Company at Tulsa is overcoming this difficulty by using the brines as cooling agents in the condensing systems in their refinery. The resulting hot water is then readily evaporated and the resulting salts are refined and sold. One of the advantageous features of this process, presumably, is that considerable bromine, which is needed for anti-knock compounds, is recovered.

The following is a list of some recent hydrological papers relating to the petroleum industry:

- Barnes, Virgil E. Oil-field waters of north-central Texas. Amer. Assoc. Petroleum Geologists Bull., v. 16, No. 4, pp. 409-411, 1932.
- Nevin, Charles M. Permeability, its measurement and value. Amer. Assoc. Petroleum Geologists Bull., v. 16, No. 4, pp. 373-384, 1932.
- Smith, J. E. Venezuelan oil-field waters. Amer. Assoc. Petroleum Geologists Bull., v. 16, No. 8, pp. 895-909, 1931.
- Soper, E. K. Limitations of ground-water as aid in determination of hidden geologic structure. Amer. Assoc. Petroleum Geologists Bull., v. 16, No. 4, pp. 335-360, 1932.
- Versluys, Jan. Can absence of edge-water encroachment in certain oil fields be ascribed to capillarity? Amer. Assoc. Petroleum Geologists Bull., v. 16, No. 2, pp. 189-200, 1931.
- Waldschmidt, W. A. Chemical analyses of oil-field waters in the Rocky Mountain province. Investigation now in progress.

In addition, the papers listed below were presented at the Oklahoma City meeting of the American Association of Petroleum Geologists, March, 1932. Abstracts will probably be published in the Pan-American Geologist within a few months.

- Brankstone, H. R., W. B. Gealy, and W. O. Smith. Improvised technique for determination of densities and porosities.
- Bryant, Howard S. Type examples where primary water occurs directly overlying commercial oil in Kansas.
- Hiestand, T. C. Primary water-occurrence directly overlying commercially productive oil-reservoirs in Oklahoma.
- Millikan, C. V. Value of bottom-hole pressures in geological interpretations.
- Snow, D. R. Water encroachment in Bartlesville sand fields of northeastern Oklahoma.
- Versluys, Jan. Factors involved in segregation of oil and gas from subterranean Water.

U. S. Geological Survey,
Washington, D. C., April, 1932.

INVESTIGATIONS OF UNDERGROUND WATER PROBLEMS IN ARIZONA,
CALIFORNIA, NEW MEXICO, AND OREGON

Arthur M. Piper

This report is a summary of investigations in progress in 1932 in the southwestern portion of the United States. It covers only those investigations that deal with water in the zone of saturation, and excludes those that deal primarily with water in the zone of aeration.

Arizona

H. C. Schwalen, Irrigation Engineer, Agricultural Experiment-Station, Tucson, Arizona, has proposed to undertake a study of the effect of pumping from wells, and of the capacity of water-bearing strata, but no report of progress is available. Several other hydrologic investigations are now being made by the Agricultural Experiment-Station, but relate primarily to infiltration and transpiration.

California

Investigations by the California Department of Public Works, Division of Water Resources--The Division of Water Resources of the California Department of Public Works is cooperating with the Bureau of Agricultural Engineering of the United States Department of Agriculture and local agencies in investigating the underground water-resources of the South Coastal Basin, of Ventura County, and of the Mojave River Basin, in southern California; of the Salinas, Santa Clara, and Napa valleys of central California; and of that part of the San Joaquin Valley which lies south of the Fresno River, also in central California.

The investigation in the South Coastal Basin is being carried on jointly by the Division of Water Resources and the Bureau of Agricultural Engineering with the advice of the Board of Consulting Engineers for southern California: Paul Bailey, A. A. Sondergerger, G. S. Hinkley, and W. P. Rowe. The investigation continues and amplifies the program outlined in preliminary reports of the Division of Water Resources (South Coastal Basin, California, Dept. Public Works, Div. Water Resources, Bull. 32, pp. 63-76, 1930; Rainfall-penetration and consumptive use of water in Santa Ana River valley and Coastal Plain, California, Dept. Public Works, Div. Water Resources, Bull. 33, 158 pages, 1930). It covers 29 sub-areas, each of which is a ground-water unit, and is planned to evolve for each sub-area a comprehensive plan for the most efficient utilization of the ground-water. The investigation may be resolved into a quantitative estimate of: (1) The capacity of each sub-area in acre-feet down to that level at which pumping becomes uneconomic; (2) the sources and amount of the present ground-water supply; (3) the present discharge by pumping, by transpiration, by ground-water overflow, and by ground-water underflow; (4) surplus or deficiency of supply with existing draft, probable future draft, and probable future depth to ground-water; (5) effect of changes in the water-supply of one sub-area on the overflow into another sub-area; (6) possible salvage of flood-waste and of waste by evaporation from water-logged land; (7) the altitude of water-table necessary to prevent incursions of salt-water from the ocean; and (8) the quantity of ground-water that necessarily will be allowed to discharge into the ocean to maintain the alkali content of the ground-water within the concentration tolerated by plant life. The principal lines of field investigation are to determine: (1) Present and past fluctuations of the water-table; (2) rainfall-penetration and consumptive use by vegetation; (3) influence of forest-cover on runoff and infiltration; (4) effects produced by spreading flood-water over absorptive areas; and (5) general geologic studies of the catchment areas and intensive geologic studies of the alluvial basins.

The storage of water underground by spreading excess surface-water on the alluvial fans is being studied by A. T. Mitchelson, Senior Irrigation Engineer, United States Department of Agriculture. This work seeks to show the rate of percolation as effected by the type of vegetal cover, by the root-systems of vegetation, by the temperature and silt-content of the surface-water, and by the fluctuations of the water-table. It continues and amplifies the work described in a preliminary report (Op. cit., Bull. 32, pp. 49-56).

In connection with the intensive geologic studies, all available well-logs have been gathered and samples are taken from each new well as it is drilled. The mechanical composition, porosity, and specific retention of these samples are determined by field tests and in a laboratory maintained by the Division of Water Resources in cooperation with Pomona College at Claremont under the immediate charge of Rollin Eakis, Assistant Engineer-Geologist. Research in the laboratory aims to evolve reliable methods for measuring the specific yield of the sediments and to relate the mechanical analysis of the sediments to the porosity, specific retention, and specific yield. These relations have been studied graphically in an effort to evolve standard curves from which the specific yield can be read if the mechanical analysis is known. It is hoped that these field and laboratory studies will lead ultimately to reliable estimates of the specific yield of the unconsolidated sediments and of the storage capacity of each of the sub-areas in the South Coastal Basin.

In conjunction with the investigations in the South Coastal Basin, H. C. Troxell, Associate Hydraulic Engineer, United States Geological Survey, is making an intensive study of fluctuations in the flow of the lower Santa Ana River in relation to consumptive use by vegetation along the bottom-lands and to evaporation. His work has shown that the discharge of the river between Riverside and the Santa Fe Railway bridge is controlled principally by the consumptive use of vegetation adjacent to the river; that the daily fluctuation in gage-height is practically the same at all points along the river irrespective of the size of the channel; that evaporation from the free water-surface accounts for only a small part of the daily fluctuation; and that the gage-height and discharge of the river are controlled mainly by the altitude of the water-table (Troxell, H. C., written communication, March 29, 1932).

The investigation by the Division of Water Resources in the Mojave River Basin aims to evolve a plan for the most economic utilization of the River. It involves observations on the present and past fluctuations of the water-table, and measurements of the percolation into the basin and the draft upon it.

The investigations in Ventura County and in the Salinas, Santa Clara, and Napa valleys likewise have as their objective a comprehensive plan for utilization of the water-supplies of the respective areas, though possibly by transfer of water from the more prolific parts of each area to those parts which are inadequately watered. Field studies are being made of: (1) Fluctuations of the water-table; (2) additions to the ground-water reservoir by losses from the streams and by downward percolation of rainfall; and (3) draft from the ground-water reservoir. In each of these areas there are available general geologic studies made by governmental or private agencies, but funds are not available for an intensive study of the unconsolidated valley fill such as is being made in the South Coastal Basin.

The investigation in the southern part of the San Joaquin Valley continues routine observations on fluctuations of the water-table in relation to stream-flow and diversions. These observations are to check conclusions reached in a previous intensive study (California Dept. Public Works, Division Water Resources, Bull. 29, 1931).

Investigation by the United States Geological Survey--In the Mokelumne region, central California, the United States Geological Survey is cooperating with the East Bay Municipal Utility District in a comprehensive study of ground-water conditions in relation to seepage-losses from the Mokelumne River, and to the effect on those losses of diverting water from the basin. The study continues and amplifies that covered by a preliminary report (Stearns, H. T., T. W. Robinson, and G. H. Taylor, Geology and water-resources of the Mokelumne area, Calif., U. S. Geol. Sur. Water-Supply Paper 619, 398 pp., 1930). The present objectives are to determine: (1) Seepage-loss from the Mokelumne River and other streams; (2) changes in ground-water storage in relation to draft by pumping and to seasonal recharge; (3) penetration of rain falling on the valley plain; and (4) consumptive use of water by natural vegetation along the River and by crops, both on the bottom-land along the River and on the main valley-plain. The work thus far has shown that although the Mokelumne River flows for a considerable distance across the alluvial plain of the Great Valley of California, the losses by downward percolation are relatively small and but little larger than the uncertainty in routine methods of stream-gaging. More effective methods are being sought for determining the specific yield of sediments, the penetration of rainfall, and the

evaporation from the soil. An intensive study is now being made of the geology of the catchment area and of the alluvial plain in relation to the hydrologic conditions.

Other investigations in California--The Division of Irrigation Investigations and Practice, College of Agriculture, University of California, is studying the effect of pumping for irrigation from the alluvial cone of Putah Creek. The investigation contemplates quantitative estimate of the safe draft on this body of ground-water. The Division is also studying the hydraulics of wells, and the movement of ground-water through water-bearing materials. It has also installed at the branch of the College of Agriculture, Davis, California, an extensive series of tanks to study losses from water-logged soil.

The United States Department of Agriculture, Bureau of Agricultural Engineering, is undertaking a study of pumping for irrigation. This project is being carried on by Carl Rohwer, Associate Irrigation Engineer, Fort Collins, Colorado. It includes field studies in California and other western States.

Measurements of depth to ground-water and observations on the fluctuation of the water-table are being made by many agencies in southern California, such as the Water Department of the cities of Los Angeles and Pasadena, the Los Angeles County Flood Control District, and the San Gabriel Protective Association.

New Mexico

The State Engineer of New Mexico, in cooperation with the United States Geological Survey, is investigating the ground-water resources of Curry, Roosevelt, and Lea counties. This area lies in the eastern part of the State adjacent to the Staked Plains of western Texas. The office of the State Engineer is also making experimental tests of the utilization of ground-water in the Animal Valley, Hidalgo County.

Oregon

The United States Geological Survey, in cooperation with the Oregon Agricultural Experiment-Station, is studying the ground-water resources of the Willamette Valley, western Oregon, of the Dalles region, north-central Oregon, and of the Harney Basin, southeastern Oregon. The Willamette Valley lies west of the Cascade Mountains in a humid region. The investigation therein is to determine the feasibility of pumping ground-water from the valley fill for supplemental irrigation to control moisture-conditions on the cultivated lands, and thereby assure optimum conditions for the growth of crops. The investigation in the Dalles region was undertaken to determine the feasibility of recovering ground-water for irrigating orchard lands located several hundred feet above the regional body of ground-water. In this area the high value of the fruit crop seems to justify an effort to recover ground-water under conditions that ordinarily would make pumping prohibitively costly. The investigation in the Harney Basin will lead to an estimate of the quantity of ground-water that can be recovered by pumping from the valley fill or from the underlying volcanic rocks for irrigation on the valley plain. In this region the surface water-supply is inadequate and so controlled by vested water-rights that widespread utilization is impracticable. The ground-water conditions are more complex than is usual in the semi-arid regions of the western United States, for both the valley fill and the underlying bed rock yield water in sufficient quantity for irrigation.

U. S. Geological Survey,
Lodi, California, April 19, 1932

ON DYNAMICS OF STREAMS

L. G. Straub

The newly appointed Committee on Dynamics of Streams of the Section of Hydrology is still in the process of organization and is just beginning to crystallize a procedure for its future activities.

The time between the appointment of this Committee and the annual meeting proved to be inadequate to allow for a report of the Committee as a whole. I am therefore taking the liberty of presenting a report which is my interpretation of the Committee's recommendations, based largely upon correspondence with the individual members.

The first formal communication to all members of the Committee was sent out in the form of a memorandum on March 4, 1932. This memorandum included a statement of the purpose of the Committee on Dynamics of Streams as outlined by Dr. O. E. Meinzer and the Executive Committee of the Section of Hydrology.

Although the proposed work seems to be definitely defined within reasonably narrow limits, the scope of its studies should be quite broad. Research in the field, laboratory, and by means of analytical mechanics should be pursued and fostered by the Committee in order that the investigations might be as comprehensive as possible.

With a view of obtaining a summary of the diversified interests of the various members of the Committee, as related to the proposed activities, the members communicated with the Chairman answering in particular a few specific questions concerning: (a) Work within scope of activities of the Committee that the member has in progress or with which he is directly or indirectly associated; (b) the possibility of pursuing special investigations particularly along the line of the Committee's activities; (c) the type of investigation the member desires to pursue (related to the Committee's activities); and (d) suggestions for work of the Committee.

A large amount of illuminating and diversified information was forthcoming. As a result of this consensus of opinion the following activities are proposed for the immediate future.

(a) The preparation of a list of societies, committees, and other organizations, both American and foreign, whose functions and activities overlap those of this Committee. It is intended that as far as possible this list should include all government and private agencies engaged in the various phases of studies related to the subjects of dynamics of streams.

(b) A second list, which is to supplement the one just mentioned, is to be compiled of individuals of note who are engaged in work which is of interest to the Committee. It is intended that both this list and the list of organizations should be disseminated eventually among all investigators occupied with work falling within scope of activities of the Committee.

(c) It is proposed to prepare a comprehensive bibliography of publications, carefully classified according to the subject-matter included and provided with sufficient description to be of value in making studies of subjects within narrowly defined limits.

(d) If a suitable means of publication can be found, it seems desirable that eventually the Committee should arrange to abstract current articles related to the dynamics of streams, appearing in various publications both in this country and abroad. Tentative arrangements have been made to print these abstracts in a special column of the journal of a national engineering society.

The foregoing activities will probably in themselves, it is believed, provide a valuable function of the Committee. This work will largely overcome unnecessary duplication of research by the various investigators concerned with the study of rivers.

There are evidently three reasonably well-defined phases of any work of the nature which the Committee might undertake. These include particularly: (a) Field observations; (b) laboratory studies; and (c) analytical studies. Furthermore, the activities seem to divide themselves into (a) the dynamic action of rain and surface runoff in soil erosion; (b) erosion and the transportation and deposition of sediment in open channels; (c) hydraulic characteristics of rivers.

The foregoing divisions and still others suggest themselves. It therefore seems possible that in the future the Committee on Dynamics of Streams might to good advantage be divided into sub-committees dealing with particular phases of the research work

proposed. In any case, however, the lines of demarcation should probably not be very rigid.

The members of the Committee on Dynamics of Streams are presenting five papers at this annual meeting which are published in these Transactions; still more papers might have been forthcoming had there been sufficient time on the program for their presentation.

Finally, it is proposed to present a symposium of papers on the dynamics of rivers at the next annual meeting, provided the Executive Committee of the Section of Hydrology finds this practicable.

University of Minnesota,
Minneapolis, Minnesota

ON CHEMISTRY OF NATURAL WATERS

C. S. Scofield, Chairman

The organization of this Committee was begun during the first months of 1932 and is still incomplete, so that the present report can serve merely to indicate the scope and character of the subjects under consideration for the Committee's program.

The professional interests of the Committee members bear on the following phases of the subject:

- (1) The chemical composition of sub-surface waters in relation to geological environment and to such geological processes as ore-deposition, and the accumulation of petroleum-deposits
- (2) The composition of sub-surface waters in relation to the corrosion of ferrous and concrete structures
- (3) The occurrence of radioactive and rare elements in spring-waters and their geological interpretation
- (4) The composition of water in relation to the processes of base exchange in geological structures and in soils
- (5) The composition of water in relation to hydrographic problems, such as the movement of underground waters
- (6) The quality of water-supplies for agricultural, domestic, and industrial use and the changes in quality consequent upon such use
- (7) The processes and conditions occurring at the contact of land-waters with ocean-waters

The proposals, or suggestions, for the work of the Committee include:

- (1) The encouragement of the publication of water-analyses
- (2) The standardization of methods of water-analysis and of methods of reporting analyses
- (3) The assembling of information concerning work in this field in progress or projected
- (4) The institution of a clearing-house to facilitate cooperation between related investigations and the interchange of results
- (5) The preparation of an index of water-analyses

The personnel of the Committee at present is listed in the prospectus issued by the Section of Hydrology under date of April 1, 1932.

U. S. Bureau of Plant Industry,
Washington, D. C.

P A P E R S

RECENT INVESTIGATIONS OF THIEM'S METHOD FOR DETERMINING PERMEABILITY OF WATER-BEARING MATERIALS

L. K. Wenzel

This paper presents results obtained in an investigation of the ground-water resources of the Platte River Valley that is being conducted in cooperation between the Conservation and Survey Department of the University of Nebraska and the United States Geological Survey.

Most quantitative ground-water studies are concerned with the amount of water that percolates into the discharge-area of an investigated region from the recharge-area in order to determine the amount of water that can be safely withdrawn from the discharge-area without an excessive lowering of the ground-water level. D'Arcy found that the quantity of water discharged through a column of water-bearing material was proportional to the hydraulic gradient, the cross-sectional area, and a constant which depends upon the material. If these three factors are known, the discharge through any cross section of a water-bearing formation may be computed.

The hydraulic gradient of an area can be obtained from contour-maps of the water-table and the cross-sectional area of the formation can be taken from well-logs, but the constant in D'Arcy's equation is more difficult to determine. This constant has been designated by various names but recently has become more or less widely called the coefficient of permeability. Norah D. Stearns, in United States Geological Survey Water-Supply Paper 596, defines the coefficient of permeability in field terms as the number of gallons a day at 60° F that is conducted laterally through each mile of the water-bearing bed under investigation (measured at right-angles to the direction of flow), for each foot of thickness of the bed and for each foot per mile of hydraulic gradient. The permeability of a material is a measure of its capacity to transmit water under pressure. Gravel and coarse sand are more permeable than fine sand and silt and therefore transmit greater quantities of water with the same hydraulic gradient.

Permeability may be determined in the laboratory by measuring the amount of water that is discharged through a sample of water-bearing material under a known pressure-head or it may be determined in the field by measuring ground-water velocities. Both of these methods are open to the criticism that the computed coefficient of permeability represents only the permeability of a small part of the entire area and consequently may differ widely from the actual average value. Moreover, the porosity and hence the permeability of a water-bearing material tested in the laboratory may be altered during the sampling and the shipping of the material. A field method for determining the average permeability of an undisturbed water-bearing formation over a comparatively large area was advanced by the German hydrologist, G. Thiem, who developed a theoretical formula by which the coefficient of permeability can be computed from pumping-tests made in the field.

Briefly, a Thiem's test is made in the field by locating two observation-wells within the cone of depression of a pumped well (Fig. 1) and by measuring the distance to the observation-wells, the thickness of the water-bearing formation, the discharge of the pumped well, and the drawdowns in the observation-wells after pumping has been carried on until the water-levels in the observation-wells are constant. The coefficient of permeability is then computed from Thiem's formula, which is in modified form

$$P = [527.7 Q \log (a'/a)]/[m(S - S')]$$

in which P = coefficient of permeability as defined by N. D. Stearns in United States Geological Survey Water-Supply Paper 596 (p. 143); Q = rate of pumping, in gallons a minute; a and a' = respective distances of the two observation-wells from the pumped well, in feet; m (water-table conditions) = average thickness (at a and a') of the saturated part of the water-bearing bed, in feet; m' (artesian condition) = thickness of water-bearing bed, in feet; S and S' = respective drawdowns at the two observation-wells, in feet.

In developing his formula, Thiem assumed a water-bearing formation of uniform permeability, a horizontal water-table before pumping, a horizontal confining-bed be-

low the water-bearing formation, and a state of equilibrium reached by the cone of depression at the time the drawdowns in the observation-wells are measured. These assumed conditions are seldom reached in the field because most water-bearing formations range widely in permeability, water-tables are not horizontal, confining-beds are irregular, and even practical equilibrium is reached only after protracted periods of pumping. Nevertheless, coefficients of permeability computed by this method may be more accurate than can be obtained by other methods because the tests permit the determinations to be made over large areas and without disturbing the formations.

Two pumping-tests were made during the summer of 1931 near Grand Island, Nebraska, to determine the accuracy of Thiem's formula and to investigate the principles of hydrology that are involved in its application. The location chosen for the tests

was about a mile from the dry bed of the Platte River where the water-table ranged from only five to ten feet below the ground-surface. A test-hole was drilled and the thickness of the water-bearing sands and gravels was found to be about 120 feet. An existing 24-inch irrigation-well, 40 feet deep, equipped with an 8-inch centrifugal pump was used for the first test, and a 12-inch well, 102 feet deep, was drilled 25 feet from the existing irrigation-well for the second test. The pump, operated by a 50-horsepower gasoline engine, was used on both wells. In order to determine drawdowns at many places on the cone of depression, 80 observation-wells were driven on lines radiating from the pumped wells (Fig. 2). About 25 of these observation-wells were three inches in diameter and 55 were one inch in diameter. All wells extended far enough below the water-table so that the water-table would not drop below the bottom of the observation-wells during periods of pumping. Measuring points were established at the observation-wells and

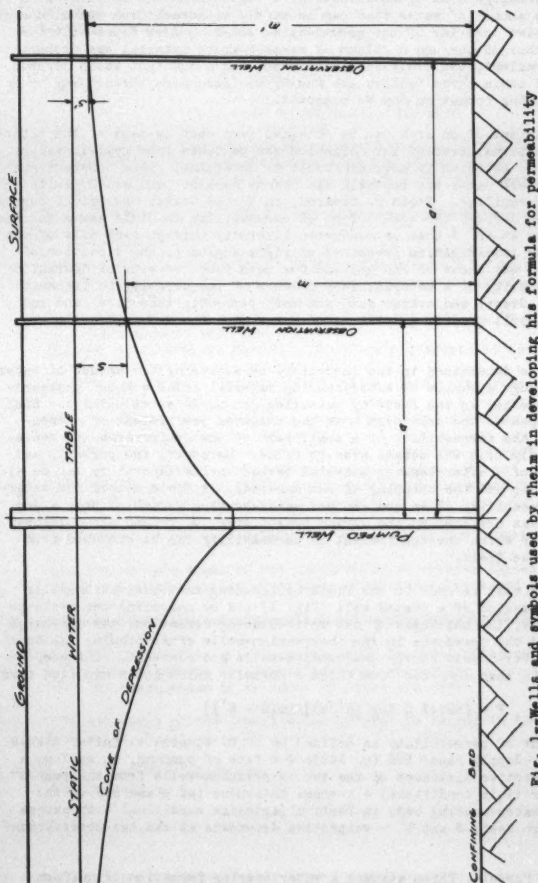


Fig. 1.--Wells and symbols used by Thiem in developing his formula for permeability

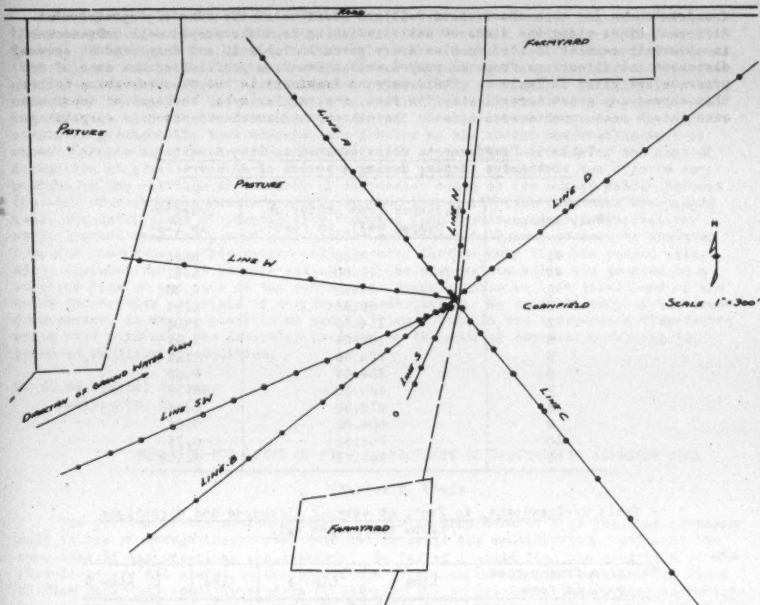


Fig. 2--Plan of pumped and observation-wells used in the pumping-tests made near Grand Island, Nebraska

elevations of these points were determined by instrumental levels. A contour-map of the water-table was then drawn with a contour-interval of one-tenth foot which showed the water-table sloping uniformly to the northeast with a gradient of 7.5 feet a mile.

At least two measurements of the depths to water in each observation-well were made previous to the starting of the tests to determine the static altitude of the water-table. Measurements were made night and day after pumping commenced so that a drawdown-curve for each well could be plotted. After pumping was completed, the program of making measurements was continued to determine the rate of recovery of the water-table.

Twelve men were required for each test of whom six measured the depths to water while six measured the discharge of the pump and conducted the water away from the well. Each well was pumped for 48 hours, and the measurements were continued from 24 to 48 hours after pumping had stopped. About 5,000 measurements were made during the first test and about 4,500 during the second. A great amount of time is required to examine so many data and at the present time this work is far from complete. Results included in this paper are based only on the first test.

Theoretically the coefficient of permeability determined by Thiem's method should be the same no matter which two of the observation-wells are used in the formula because the only variables are the distances of the two observation-wells from the pumped well and the drawdowns in these wells. Thus to make a complete study of the applicability of the formula to field conditions it was necessary to devise a method whereby the drawdown of the water-table at any distance from the pumped well could be determined for any time during the period of the test. This was accomplished by plotting a

drawdown-curve for each observation-well and profiles of the cone of depression at different times along the lines of wells radiating from the pumped well. Drawdowns in observation-wells located on line A are given in Table 1, and drawdowns at several distances and directions from the pumped well taken from profiles of the cone of depression are given in Table 2. There were no drawdowns in the 80 observation-wells that showed any great irregularity; in fact, the regularity of the cone of depression even though measurements were made to the nearest hundredth of a foot is surprising.

Table 1--Drawdowns in wells located on Line A, after continuous pumping during a period of 48 hours

Well number	Distance from center of pumped well, in feet	Drawdown, in feet
71	2.62	8.96
72	12.30	5.12
1	24.92	4.03
2	59.86	2.81
3	114.36	2.03
4	164.24	1.62
5	228.96	1.14
6	354.08	0.65
7	429.30	0.52
8	473.85	0.44
9	604.02	0.26
10	754.51	0.15
11	903.76	0.105

Table 2--Drawdowns, in feet, at several distances and directions from the pumped well

Distance from pumped well in feet	Line A	Line B	Line C	Line D
50	3.06	3.14	2.98	2.93
100	2.17	2.11	2.08	2.20
150	1.74	1.57	1.52	1.68
200	1.35	1.22	1.17	1.34
300	0.87	0.74	0.73	0.86
400	0.57	0.46	0.44	0.56
500	0.41	0.29	0.28	0.37
600	0.28	0.20	0.20	0.25
800	0.13	0.09	0.10	0.11

The most important departure of field conditions from the formula is shown in Table 3 and is due to the fact that pumping could not be continued until there was no further decline of water-level in the observation-wells.

Table 3--Coefficients of permeability computed by Thien's formula using $a = 50$ feet and a' equal to several distances

a' in feet	$(S - S')$ in feet	P
75	0.64	666
100	1.03	696
150	1.50	723
200	1.92	745
300	2.40	766
400	2.68	802
500	2.85	835
600	2.94	873
700	3.00	909
800	3.06	925

When pumping starts, the water-table is first lowered close to the pumped well and then, as pumping continues, the water-surface is lowered at gradually increasing distances. This lag in the decline of the water-table makes the difference of drawdowns, $(S - S')$, as substituted in the denominator of Thiem's equation too large and consequently makes the computed coefficient of permeability too small. This lag is seen clearly by taking S as the drawdown in an observation-well close to the pumped well and using in turn the drawdowns in more distant observation-wells as S' . The coefficients of permeability thus computed are greater as the second observation-well is chosen farther and farther from the pumped well because the altitude of the cone of depression at greater distances from the pumped well is relatively too high in comparison to the altitude of the cone of depression close to the pumped well. Because the cone of depression has more nearly reached its equilibrium form near the pumped well, the coefficient of permeability computed from drawdowns in two observation-wells located near the pumped well will be more accurate than coefficients computed from the drawdowns in observation-wells located farther away from the pumped well. Also, computations will be more reliable if the observation-wells are located on a straight line on one side of the pumped well because there is less likelihood of the wells penetrating materials of varying permeabilities. By careful study of the drawdown-curves, it may be possible to modify Thiem's formula and introduce a time-factor which will eliminate the deviation produced by the cone of depression failing to reach an equilibrium-condition.

U. S. Geological Survey,
Washington, D. C.

EQUATION FOR LINES OF FLOW IN VICINITY OF DISCHARGING ARTESIAN WELL

Charles V. Theis

The problem of the motion of water in the neighborhood of a discharging artesian well is one of enough theoretical interest to merit its consideration, while at the same time it has practical applications. So far as I could find the equations of the flow-lines are not stated in the literature except as the general equation for lines of flow under all conditions given by Slichter (C. S. Slichter, Theoretical investigation of the motion of ground-water, U. S. Geol. Sur., Nineteenth Ann. Rept., pt. 2, pp. 333-336, 1899).

The application of the general equation to the specific case is not apparent to one not familiar with the mathematics of hydrodynamics. I am therefore venturing to give a derivation of this special case in the hope that others may find the results valuable.

Let us assume a homogeneous artesian bed of uniform thickness, the piezometric surface of which is a plane. Let the slope of this surface and therefore the direction of flow under natural conditions be taken as the X-axis. Let the origin of the coordinates be placed at the well. Let θ = the velocity of a water-particle under undisturbed natural conditions. When the well is discharging this velocity will be combined vectorially with another velocity, v , directed toward the well. v varies inversely with the distance of the particle from the well, r . At some distance from the well V will equal in absolute magnitude the normal velocity θ . Call this distance ρ . Then

$$|v| = \left| \frac{\theta \rho}{r} \right| = \left| \frac{\theta \rho}{\sqrt{x^2 + y^2}} \right| \quad (1)$$

The physical meaning of ρ may be grasped by considering that as it is the distance where $v = \theta$ in absolute magnitude, it must be the distance where the two components of the resultant velocity neutralize each other on the "downstream" side of the well. It is therefore the distance to the ground-water divide directly downstream from the well.

If we express this radial velocity in terms of its components in the x- and y- directions and combine it with the normal velocity, θ , we have

$$\frac{dx}{dt} = \theta - \frac{x}{\sqrt{x^2 + y^2}} - \frac{\theta p}{\sqrt{x^2 + y^2}} = \theta \left(1 - \frac{x p}{x^2 + y^2}\right) \quad (2)$$

$$\frac{dx}{dt} = \theta \left(\frac{x^2 + y^2 - x p}{x^2 + y^2}\right) \quad (3)$$

The negative signⁱⁿ (2) shows that the velocities are additive when the particle is to the left of the origin (when x is negative) and subtractive to the right of the origin.

Similarly for the velocity in the y -direction:

$$\frac{dy}{dt} = - (y/\sqrt{x^2 + y^2}) (\theta p/\sqrt{x^2 + y^2}) \quad (4)$$

$$\frac{dy}{dt} = - \theta p y / (x^2 + y^2) \quad (5)$$

The negative sign in (4) indicates that the course of the particle is downward for positive values of y .

Dividing (5) by (3)

$$\frac{dy}{dx} = - p y / (x^2 + y^2 - p x) \quad (6)$$

Solving this differential equation

$$(x^2 + y^2) dy - x p dy + y p dx = 0$$

$$dy + p(y dx - x dy) / (x^2 + y^2) = 0$$

$$y + p \tan^{-1} (x/y) = C \quad (7)$$

$$x = y \tan [(C - y)/p] \quad (8)$$

This is the general equation for all lines of flow under the assumed conditions. The constant, C , determines the particular line of flow to be investigated. The quantity $[(C - y)/p]$ is, of course, measured in radians.

The particular line of flow of most general interest is that one which traces the ground-water divide and separates the water which ultimately enters the well from that which does not. It is evident that the point $(p, 0)$ lies on this flow line. Substituting this value in (7) we obtain:

$$C = p \tan^{-1} (p/0) = p \tan^{-1} \infty$$

$$C = \pi p / 2 \quad (9)$$

The equation for the ground-water divide is, therefore, from (8)

$$x = y \tan (\pi/2 - y/p) \quad (10)$$

Values for this equation are

y	$y \tan (\pi/2 - y/p)$	x
∞	$\infty \tan (-\pi/2)$	$-\infty$
3.0 p	3.0 $p \tan (-1.4292)$	-27.459 p
2.5 p	2.5 $p \tan (-0.9292)$	- 3.335 p
2.0 p	2.0 $p \tan (-0.4292)$	- 0.906 p
1.5 p	1.5 $p \tan (0.0708)$	+ 0.106 p
1.0 p	1.0 $p \tan (0.5708)$	+ 0.642 p
0.8 p	0.8 $p \tan (0.7708)$	+ 0.776 p
0.6 p	0.6 $p \tan (0.9708)$	+ 0.88 p
0.4 p	0.4 $p \tan (1.1708)$	+ 0.946 p
0.2 p	0.2 $p \tan (1.3708)$	+ 0.985 p
0.0	0.0 $\tan (\pi/2) = 0. \infty$	+ 1.000 p

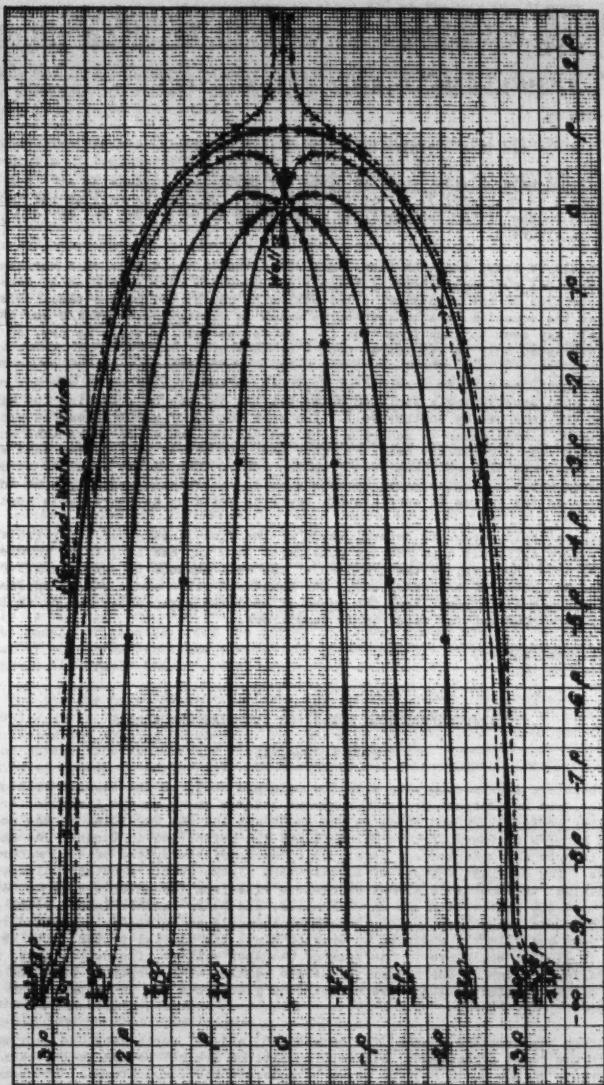


Fig. 1--Lines of flow to artesian well (The small circles and crosses indicate computed points)

The constant for any other flow-line can be computed by assuming one point on it and substituting the coordinates of that point in (7). Thus, for a particle originating at $(-\infty, 3\pi/4)$

$$C = 3\pi/4 + \rho \tan^{-1} (-\infty/y) = 3\pi/4 - \pi/2 = \pi/4$$

and the path is

$$x = y \tan (\pi/4 - y/\rho)$$

The ground-water divide, the flow-lines for particles originating at $(-\infty, 3\pi/4)$, $(-\infty, (\pi/2))$, $(-\infty, (\pi/4))$, and $(-\infty, 0)$, as well as the two flow-lines, close to the divide, of particles originating at $(-\infty, 3\rho)$ and at $(-\infty, 3.2\rho)$ are given in Figure 1.

It should be noted that the flow-lines are actually the traces on a horizontal plane of vertical surfaces extending through the aquifer. All particles of water in the same position on the plan-view, irrespective of depth, follow the same course. Further, as the equation is a tangent-curve which is discontinuous at $\pi/2$ and $3\pi/2$, the particle may seem to jump from $+\infty$ to $-\infty$ for certain values. We are, of course, interested only in its course from $-\infty$ to $+\infty$.

These equations furnish a method of approach to the problem as to whether or not a drainage well penetrating a confined water-bearing bed may be polluting the water drawn from the same bed by another well. The same method of solution can be applied to the case of a well which is fed by a confined aquifer and which leaks into another aquifer under less hydrostatic head. In this case the curves will be the same except for sign; they will diverge downstream from the well. Thus, it is possible to determine the area which is contaminated by such a well. A drainage well may come into this class when the inflow is sufficiently rapid to build up an appreciable head.

A mathematically accurate determination of the flow-lines under water-table conditions is more difficult than the one considered here and has not, to my knowledge, been worked out. However, if the drawdown of the well amounts to only a small fraction of the thickness of the water-body, the equations given above can be applied with probably only a small error. Thus the types of problems given above may be at least approximately worked out for water-table conditions.

U. S. Geological Survey,
Washington, D. C.

CHARACTERISTICS OF RUNOFF OF SOUTHEASTERN ALASKA

Fred F. Henshaw

Southeastern Alaska comprises a narrow mainland strip on the seaward side of the Coast Range, and an adjacent group of numerous islands known as the Alexander Archipelago lying between Portland Canal on the southeast and Mt. St. Elias on the northwest, and between northern British Columbia and the North Pacific Ocean. The mainland and islands are indented and separated by an intricate system of deep waterways and fiords. The dominant feature of southeastern Alaska is its mountainous character. On the mainland the mountains almost everywhere rise from the water's edge to heights of 2,000 to 4,000 feet within two to four miles, and peaks farther inland reach altitudes of 5,000 to 10,000 feet. The land-forms indicate an intensely glaciated region that has been but slightly modified by erosion since the glacial period, with abundant evidence of glacial sculpture in the form of U-shaped valleys, fiords, cirques, and hanging valleys. Many of the higher ridges are mantled with perpetual snow and ice, and some of the mountain valleys are occupied by glaciers a few of which extend to tide-water.

Although southeastern Alaska lies between 55° and 60° north latitude, corresponding to the coast of Labrador, climatic conditions are not severe as the warm ocean-currents of the North Pacific serve to moderate the temperatures. The mean yearly temperature at sea-level ranges from about 44° at Ketchikan and Sitka, both of

which are well exposed to the sea, down to about 40° at Skagway and Stewart, both located near the heads of long inlets and near the Canadian border. The recorded precipitation ranges from 166 inches at Ketchikan to 26 inches at Skagway.

For the stream on which records are available the mean depth of runoff ranges from 100 to more than 250 inches. For 26 gaging-stations for which drainage areas have been measured it averages 172 inches.

The United States Geological Survey has recently issued Bulletin 836-C, Surface Water-Supply of Southeastern Alaska, 1909-1930, which makes available for the first time in print the results of stream-measurements made during the past ten years by the Forest Service and by permittees and licensees of the Federal Power Commission, which have continued and supplemented earlier work by the Geological Survey. This publication presents monthly discharge-records for 35 gaging-stations, ranging in length from two to fifteen years.

Thus, for the first time the data have become available for a comparison of runoff-conditions in southeastern Alaska with those in the United States and Canada for which records have been available for a considerable time.

A convenient index of the characteristics of any periodic natural phenomenon, as regards its variability from year to year, commonly called the coefficient of variation, is derived by expressing each value of a series in terms of its deviation from the mean, and taking the square root of the averages of the squares of the deviations. This has been computed for the yearly runoff of eight streams in southeastern Alaska on which are available records covering ten years or over, not necessarily continuous, and has been found to vary from 0.16 for Mahoney Creek near Ketchikan, down to 0.10 for Long River and Crater Creek near Juneau, and to average just 0.12. It is slightly higher for the northern streams but this tendency is not conclusively indicated.

The coefficient of variation of yearly runoff has been computed for more than 40 streams in Washington and Oregon, and found to vary from 0.60 to 0.13. For seven streams draining the western slope of the Cascade Range in Oregon it averages 0.19; for eleven streams on both the slopes of the Cascade Range in Washington it also averages 0.19. It is 0.17 for Columbia River and 0.13 for the Deschutes. For the former the relative uniformity is probably due partly to the large expanse of the basin, and partly to the high and relatively uniform precipitation in the mountains in which most of its runoff originates. For the latter it is due almost entirely to the regulating effect of the porous soil and subsoil and to the copious springs through which the Deschutes is largely fed.

The streams in southeastern Alaska are not spring-fed. Their minimum flow is generally quite low, and their areas are predominately small. Some of them rise in snow fields and small glaciers, but for those on Revillagigedo Island the drainage basins have a moderate average elevation and contain no permanent snow-fields. Uniformity of runoff is essentially the result of the uniformity of precipitation from year to year.

It is notable that without exception, for streams in southeastern Alaska on which records cover a considerable period, the year 1931 is one of high runoff. For three streams near Ketchikan it is the highest on record. For 1930, all but one of the streams gave a runoff in excess of normal. Both 1930 and 1931 were years of drought in Washington, Oregon, and California, in which a large percentage of the records of low runoff were broken. Whether the occurrence of a wet year in the north and a dry one in the south is entirely fortuitous, or whether there is a distinct tendency for the cycle of rainfall or runoff to reverse in areas of extremely high runoff, one can only conjecture. It has been suggested that practically the same amount of moisture may reach the Pacific Coast littoral each year; that drought in California and Oregon may be caused by the northward deflection of moisture-laden winds and accompanied by an abnormally high precipitation in Alaska. Records are not yet available for an adequate test of this hypothesis.

For areas of moderate elevation in the southernmost islands of the Alexander Archipelago, the yearly hydrograph is usually characterized by two low-water periods, one generally culminating in August, the other in February or March; the former re-

sulting from the termination of rapid melting of the preceding winter's snow, the latter by cold, dry weather in midwinter. There are normally two periods of relatively high water, one extending from about September to December and the other from April to about the first of July--the former due to heavy autumn rains, the latter to the melting of winter snows. Frequently one of the low-water periods may fail to appear, resulting in eight or ten months of fairly uniformly high runoff. The runoff of such streams can be regulated to a uniform flow with a relatively low storage-capacity.

On the other hand, the streams rising on the mainland in the high coast range, have only one low-water period, lasting generally from December to April. During an unusually cold winter it may continue unbroken; again it may be broken by short periods of fairly high water, generally affecting only the lower reaches of the stream. Unless the gaging-station is located just below the outlet of a lake the accuracy of winter records may be seriously affected by ice-obstruction. However, minimum discharges generally occur late in March or April, after the ice has disappeared from the lower courses of the stream, and may thus be accurately determined.

These high-level streams generally start to rise steadily late in April and experience from May to August fairly continuous high stages. This runoff comes almost entirely from melting snow as May, June, and July are months of relatively low precipitation. After most of the accumulated snows are gone, the late summer and autumn rains tend to cause floods of short duration with intervening low periods which may last until November or December. After some time in December stages gradually recede to the low water of midwinter.

The streams of the southeastern Alaska mainland of which Long River, a tributary of Port Snettisham about 30 miles southeast of Juneau may be taken as fairly typical, have runoff-characteristics similar in a broad way to those rising in the high Sierra Nevada in California, and in the more elevated portions of the Cascade Range in Oregon and Washington. The principal differences are that high water from melting snow lasts longer on the Alaska streams, and the flashy floods resulting from rains tend to come in September to November, instead of in December to March as in California and Oregon.

On the Rocky Mountain streams in the headwaters of Columbia River in Montana and British Columbia, flashy floods are practically lacking. For Flathead River, Montana, high water extends from May to August; 70 per cent of the average year's runoff occurs in these four months, while on Long River it is about 58 per cent.

This relatively uniform distribution of flow through the year, combined with the uniformity of yearly averages, tends to make possible a high degree of utilization of these streams, with relatively small storage. Thus it would have been possible to completely regulate the flow of Long River for the eleven years from October, 1918 to October, 1929, with 190,000 acre-feet of storage or about 60 per cent of the average yearly runoff. The flow of Fish Creek on Revillagigedo Island might have been rendered uniform from November, 1917 to May, 1926, 8-1/2 years, by the use of 150,000 acre-feet of storage, or practically 50 per cent of the average yearly runoff.

By way of comparison it appears from Plate III of Water-Supply Paper 486 of the Geological Survey, that the flow of Wenatchee might have been completely regulated during nine years, 1909 to 1918, by the use of 1,260,000 acre-feet, or 78 per cent of the mean annual runoff.

Federal Power Commission,
Washington, D. C.

CERTAIN FLOOD-FLOW PHENOMENA OF IOWA RIVERS

Floyd A. Nagler

1. Elongated water-sheds of Iowa streams--The characteristic long and narrow water-sheds of Iowa rivers produce unique phenomena in flood hydrographs capable of analysis to a degree not possible for most streams with fan-shaped water-sheds. The principal Iowa rivers originate in Iowa or Minnesota near the Minnesota border and flow diagonally across the State. The basins are usually narrow, with a length 8 to 30 times their average width.

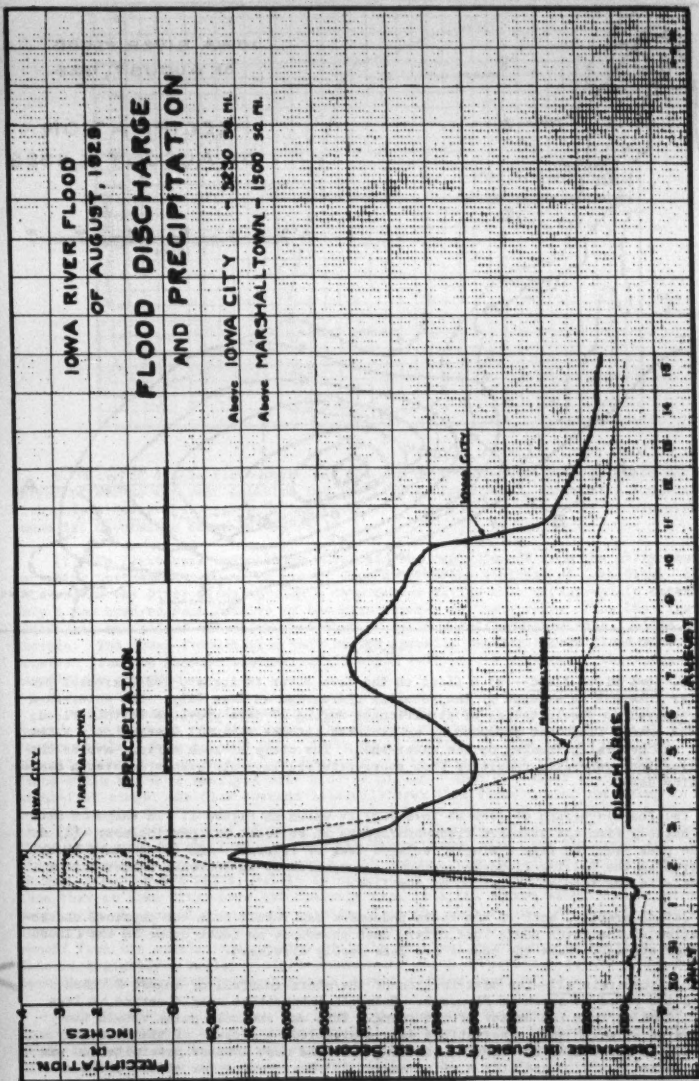


FIG. 1

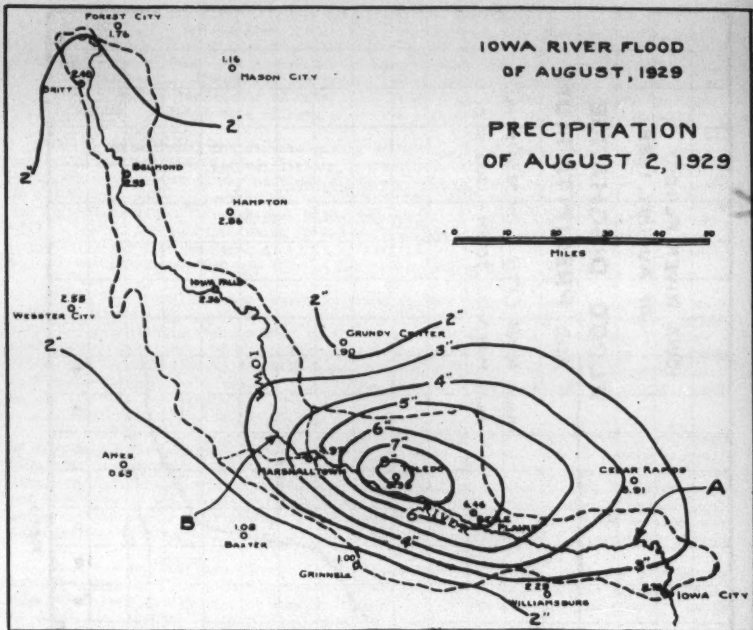


Fig. 2

2. Iowa River flood--(a) A flood on the Iowa River in August, 1929, aroused particular interest on account of the peculiar hydrograph at Iowa City. The water-shed had received no precipitation of significance during 17 days previous to this flood, and the entire flood was produced by an isolated intense rainfall lasting only a few hours and centrally located on the water-shed. The study of such a flood avoids the complications generally resulting from storm-rainfall unevenly scattered over a number of rainy days.

(b) The hydrograph of flow at Iowa City is shown in Figure 1. In shape it differs notably from the standard flood-hydrograph in at least two particulars: (1) A double peak resulted from a single isolated leak of rainfall; and (2) a sharp break occurred in the falling flood-hydrograph, accompanied by an increase rather than a decrease in the rate of depletion of the flow.

(c) Apparently, both of the above phenomena may result from the physical characteristics of the river above Iowa City. Such phenomena no doubt occur in the floods of other streams, where the causes are less easily disclosed.

3. Storm-rainfall--The distribution of the storm-rainfall of August 2 which caused the flood is shown in Figure 2. Rainfall intensities were observed at Iowa City, 70 miles from the center of the storm. This was the only point within the storm-area at which such observations were available. The graph of the Iowa City rainfall is reproduced on Figure 3, showing that the most intense precipitation was received between 4:00 and 5:45 a.m. on August 2. Near the center of the storm at Toledo, it was reported that most of the 8-inch rainfall was received between 11:00 p.m. on August 1 and 3:00 a.m. on August 2.

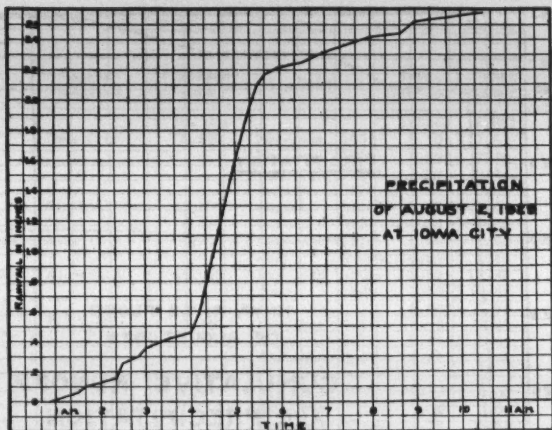


Fig. 3

4. Cause of double flood-peak--(a) The manner in which the precipitation was received offers no apparent solution for the double flood-peak. Likewise a long river with only minor tributaries entering along its stem would not normally be expected to cause the phenomenon shown in Figure 1.

(b) The first peak undoubtedly resulted from rapid runoff from the hilly country extending upstream for 25 miles (to A, Fig. 2) from the vicinity of Iowa City. In this region the River flows through a deep narrow valley with a flood-plain extending only a few hundred feet outside of the main channel of the stream. Thus the first flood-peak had all of the characteristics of rapid runoff combined with limited channel-storage. The local freshet from this region actually receded before flood-water was received from the heavier storm-rainfall which fell on the portion of the water-shed immediately upstream.

(c) The second peak following five days later had all the characteristics of flow retarded by storage. In this case, the storage utilized was in the valley of the stream itself. From point A (Fig. 2) to point B (Fig. 2), the latter upstream about 100 miles, the valley of the Iowa River is one to three miles in width, with a present flood-plain which is nearly a mile wide in places. When the River rises above an eight-foot stage, the flow spreads laterally over this flood-plain, resulting in a reduction in the flood-peak by the storage of a large volume of flood-water in the valley. The rate of progress of the flood-peak is likewise retarded. The simultaneous flood-hydrograph of the Iowa River at the Marshalltown gage near the upper end of the storage-area is also shown in Figure 1. At Marshalltown the River drains a water-shed of only 1,600 square miles, yet it is noted that the peak-flood discharge was higher than that at Iowa City where the drainage area is 3,250 square miles. Also, at this point only one normal flood-peak resulted from the same storm. As the flood moved downstream from Marshalltown the peak-discharge decreased even though it was joined by runoff from the smaller tributaries draining the land receiving the heaviest rainfall. This is typically a valley-storage phenomenon, which effectively retarded the runoff, spreading the second flood-peak over a period of five days.

(d) The double flood-peak has been quite commonly observed in other floods on the Iowa River whenever isolated storm-rainfall falls on the water-shed in the vicinity shown in Figure 2. It does not result when storms are confined to the upper portion of the water-shed or from storms concentrated in the vicinity of Iowa City. The first peak is often higher than the second, depending upon the location and magnitude of the storm. This phenomenon has also been observed on other Iowa streams with similar physiographic conditions.

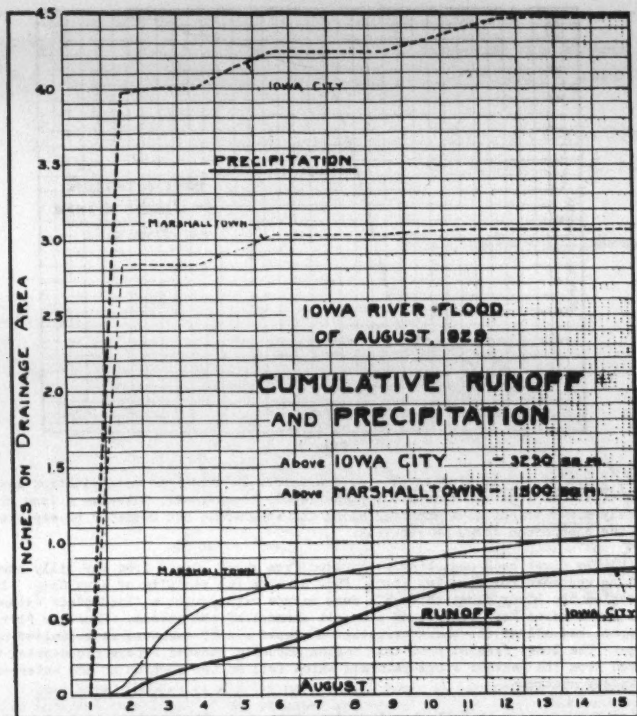


Fig. 4

5. Cause of break in rate of falling flood--(a) It will be noted that the break in the hydrograph of the falling flood occurred at a discharge of approximately 6,000 cubic feet per second. This phenomenon has been observed at Iowa City whenever flood-peaks originate from isolated storm-rainfall over the upper and middle portion of the water-shed. The break in the flood-graph generally occurs when the receding flood at Iowa City has fallen to a discharge between 6,000 and 8,000 cubic feet per second.

(b) The capacity of the Iowa River above Iowa City at bankfull stage is likewise equivalent to approximately 6,000 to 8,000 cubic feet per second. This fact at once suggests the cause for the break in the receding hydrograph. As long as a large amount of valley storage is available to replenish the flood-flow, the rate of recession is slow, but when this reservoir of flood-water has been exhausted, the flood-flow is sustained only by the relatively small amount of storage within the river banks. Hence, as some have expressed it, "the bottom appears to drop out of the river," and the stream rapidly falls to a normal stage, where the discharge can be maintained by the inflow from the various tributaries. In floods, with rainfall scattered in time and distribution over the water-shed, the above effect is often entirely obscured.

6. Percentage of runoff--(a) It is fortunate for agriculture in Iowa that the percentage of runoff from storm-rainfall is small. In the August 1929 flood, the percentage of the precipitation reaching the stream, amounted to only 18.3 per cent at

Table 1--Percentage runoff of typical Iowa summer floods

River	Gaging-station	Drainage-area	Date	Total precip.	Total runoff	Per cent runoff of precip.
		sq. mi.		inches	inches	
Iowa	Iowa City	3,230	May-June 1903	7.10	1.68	22.3
			May-June 1918	6.99	2.56	33.8
			June-July 1924	4.72	0.84	17.8
			August 1929	4.48	0.82	18.3
Iowa	Marshalltown	1,500	August 1929	3.07	1.05	34.2
Cedar	Cedar Rapids	6,570	May-June 1903	5.75	1.09	19.0
Des Moines	Kalo	4,290	May-June 1915	5.34	1.66	29.2
			July 1920	4.63	1.36	30.0
Des Moines	Keosauqua	14,090	May-June 1903	8.53	2.59	30.4
			June 1906	1.92	0.49	25.6
Raccoon	Van Meter	3,450	May-June 1917	5.86	1.79	30.5
			May-June 1916	6.46	1.81	28.0
			May-June 1917	5.95	1.88	31.6
			September 1926	4.62	1.79	38.8
Skunk	Coppook	2,915	May-June 1917	7.16	2.89	40.0
			May-June 1918	7.16	2.00	28.0
			June-July 1924	3.78	1.36	36.0
			Sep.-Oct. 1926	12.56	4.58	36.4
Skunk	Augusta	4,285	May-June 1917	6.91	2.90	42.0
			May-June 1918	6.10	1.64	26.9
			June-July 1924	4.38	1.80	41.1
			Sep.-Oct. 1926	12.85	5.40	42.0
Skunk	Ames	315	June-July 1924	2.54	1.40	55.1
Squaw Cr.	Ames	205	June-July 1924	2.29	1.54	67.3
			Sep.-Oct. 1926	12.85	3.35	26.1
Ralston Cr.	Iowa City	3.0	June 1926	2.65	0.49	18.6
			September 1926	1.98	0.78	39.4
			September 1926	1.84	0.82	44.6
			May 1927	1.04	0.32	30.7
			May 1927	1.23	0.59	48.0
			May 1927	0.59	0.41	69.5
			June 1927	4.88	3.05	62.4
			June 1928	2.06	0.52	25.0
			July 1928	1.35	0.19	13.8
			July 1928	1.07	0.45	41.7
			August 1928	1.61	0.61	37.9
			August 1928	3.30	0.90	27.0
			June 1929	1.77	0.34	25.4
			June-July 1929	2.54	0.71	27.9
			August 1929	2.76	0.76	27.5
			June 1930	4.17	1.52	36.3
			June 1930	1.11	0.19	17.2
			September 1930	5.07	1.28	25.2

Iowa City and 33.7 per cent at Marshalltown. Experiments indicate that very little, if any, of the midsummer precipitation percolates deep enough into the soil to replenish the ground-water and replenish the supply available for subsequent runoff. Hence, the balance of the water was either evaporated immediately or stored in the upper layers of the soil for future evaporation and plant use. The graph showing the comparison of the cumulative runoff and precipitation is shown in Figure 4.

(b) In Table 1, the percentage storm-rainfall appearing as flood-runoff is listed for other midsummer floods on Iowa streams. On the larger basins, the flood-runoff rarely exceeds 30 per cent of the precipitation, although occasionally on some smaller water-sheds almost 70 per cent of the storm-rainfall has reached the streams.

University of Iowa,
Iowa City, Iowa

FORCES ACTING ON SOIL MOISTURE IN RELATION TO OTHER FUNDAMENTAL FUNCTIONS

N. E. Edlefsen

It will be convenient for the purpose of our discussion to consider the water in soil as held in three different manners: (1) Water in the liquid-air interface; (2) water in the solid-liquid interface; (3) water in between these two surfaces. A considerable amount of study has been given to each of these divisions by various investigators. Most of the water in soil is held in the last form but its condition as regards pressure or potential depend on the shape of the interfaces. Of course, it must be kept in mind that from a mathematical sense there is no discontinuity in passing from one division to another, but from a physical point of view there is a more or less sudden change.

In order to comprehend the equilibrium-condition of water, it is helpful to note the difference in the nature of the forces involved.

Laplace and Gauss treated capillary phenomena as problems in statics. Both of these physicists although developing the problem in slightly different manners considered the molecules as being in a state of rest. Such a conception is not in accord with our ideas of the nature of heat, in which we assume the molecules to be in a state of incessant and fortuitous movement. In their treatment of the subject, Laplace and Gauss gave dimensions to their elements of volume which were large compared with molecular dimensions. In this case they considered quantities as being the average values with respect to time. In order to comprehend the state of conditions at equilibrium in treating the subject of capillarity with Laplace and Gauss, we must introduce a force to replace the kinetic pressure. In order to demonstrate the difference in the forces involved it will be helpful to refer to Figure 1. Let ECDF be a

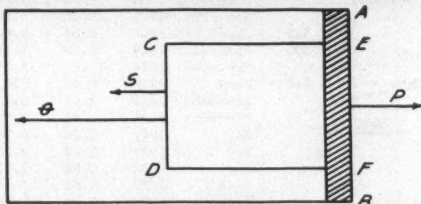


Fig. 1--Diagrammatic representation of forces acting on elemental volume of water

rectangular parallelepiped of liquid adjacent to the wall AB of a vessel. The resultant S of the forces of cohesion on ECDF may be represented by the arrow pointing into the liquid whereas the kinetic pressure θ may be represented by an arrow pointing to the left. The exterior pressure P on EF may be represented by an arrow pointing to the right. The equilibrium condition may be expressed by $P = (\theta - S)$.

Let $(\theta - S)$ represent the pressure in any direction. The kinetic pressure θ may, for all practical purposes, be considered as of the nature of a force applied at the surface, whereas, the cohesion S is characterized by a force field. We see here essentially three different types of forces: A body force characterized by a force field, a surface force, and what might be termed a kinetic pressure.

We have, of course, neglected in this example the force of gravity which is a force field acting in a direction perpendicular to the other forces as shown in the Figure. In practically all capillary phenomena, one has to consider these three types. It will be helpful to consider a water-wedge as shown in Figure 2. Let us construct a horizontal plane as indicated at a distance from point B, the lowest point on a meniscus of a mass of liquid equal to the radius of the sphere of activity. The hydrostatic pressures under this plane are in equilibrium around the line BB". This is also the case with the kinetic pressure around BB", but, in the case of the molecular attractive forces acting on the mass above the horizontal plane, they depend

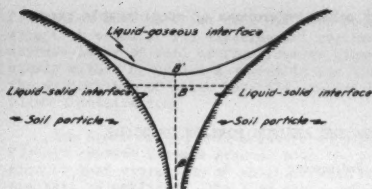


Fig. 2--Diagram of water-wedge between soil-particles

on the form of the meniscus since they have a field of force. The form of the surface is governed by the relative magnitude of the cohesive and adhesive forces. In case of water in soil it is concave away from the water-wedge. The hydrostatic pressure of the liquid in the capillary wedge is therefore determined by the difference between the molecular attractive forces and kinetic forces. The relative magnitude of these forces depend on the temperature and the quantity of water in the soil as well as the size and position of the element of volume or element of surface considered, so that when one speaks of the force on soil moisture, it is necessary to be clear as to whether it is force per unit of mass or force per unit of area.

The above method of regarding the problem is especially useful from some standpoints.

The equation of motion of soil moisture is

$$\frac{dv}{dt} = F - \frac{1}{\rho} \nabla p + \frac{\mu}{\rho} (\nabla \nabla \cdot \frac{v}{3} + \nabla \nabla \cdot v)$$

where v = velocity, ρ = density, p = pressure, ∇ = the vector-operator, and μ = coefficient of viscosity.

Space will not permit much discussion of the equation but the special case where $\frac{dv}{dt} = 0$ and $v = 0$ may be considered briefly. In this case

$$F - \frac{1}{\rho} \nabla p = 0$$

F represents the external body forces. These are gravity and external molecular attraction. For most soil-moisture problems gravity is the only one which need be considered. For example at field capacity, that is, the maximum amount of water the soil will hold and be in equilibrium under the pull of gravity, we have

$$\nabla \phi = \frac{1}{\rho} \nabla p$$

where ϕ represents the gravitational potential.

However, at lower moisture-contents experiments suggest that other forces become of sufficient magnitude to be of importance. Consider the typical curve representing vapor-pressure of water in soil as a function of moisture-content for example. There is a sharp change in the slope at a particular moisture-content which, of course, means that the amount of energy per unit mass required to extract moisture from the soil changes very rapidly at this point, whereas, for all higher moisture-contents the curve is comparatively flat. It is also significant in this connection that plants permanently wilt at about this same moisture-content, and that they are able to extract water at about the same rate for all moisture-contents above this value.

This seems to suggest that at this moisture-content the moisture occurs largely in the solid-liquid interface, that is, in the region influenced by the molecular attraction of the solid soil-molecules for the water-molecules.

[The following list of references represent especially important contributions to the subject of soil moisture, to which it would be desirable to refer:

- W. B. Haines, *J. Agric. Sci.*, v. 17, pp. 264-290, 1927, and v. 20, pp. 97-116, 1930.
 R. A. Fisher, *J. Agric. Sci.*, v. 16, pp. 492-508, 1926, and v. 18, pp. 406-410, 1928.
 W. Gardner, *Soil Sci.*, v. 7, pp. 313-317, 1919, and v. 10, pp. 357-358, 1920.
 H. Green, *Soil Res.*, v. 2, pp. 233-263, 1931.

The last article referred to contains many other references of considerable importance.--Ed.]

University of California,
Davis, California, April 1932

THE DISPOSAL OF MOISTURE FROM THE AERATED PORTION OF SOILS

F. J. Veihmeyer

The disposal of water applied to the soil may be accounted for in a number of ways which may be listed as follows:

- (1) Losses by runoff
- (2) Evaporation from the free water-surfaces while the water is being applied
- (3) Deep percolation below the reach of roots of plants
- (4) Seepage losses along impervious strata below the surface
- (5) Evaporation directly from the surface of the soil
- (6) Water used by plants
- (7) Water remaining in the soil

Generalizations are hardly possible with any of these items except (5) and (6) since they are controlled entirely by local conditions. The last three items have been the subject of extensive investigations in California. Inasmuch as the summer months when most of this work was done were rainless and further characterized by relatively high temperatures and low relative-humidities, the experiments were carried on under most favorable conditions for such studies. This paper is a very brief summary of some of the results obtained.

When water is applied to a soil the pore-spaces are completely filled for a short time. During this interval the soil is saturated. If drainage is permitted to take place, some of the water will move downward by gravity. The presence of gravitational water in drained soils is of short duration. The amount of water retained by the soil after "drainage takes place" has been referred to in a number of ways. The use of the term "field capacity" seems to be the one best adapted for general use. It may be defined as that amount of water held in the soil after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased, which usually takes place within two or three days in pervious soils of uniform structure and texture. The field capacity of a soil is influenced by a number of factors, the most important of which are texture, structure, uniformity, and depth. The moisture-equivalent gives a fair measure of the field capacity of fine-textured soils, but not of all sands.

After an application of water the soil throughout the portion wetted is, to a uniform moisture-content, the field capacity, as far as can be detected with the means of sampling field soils which are now available. The downward movement of water in soils is due almost entirely to gravity and not to capillary movement. Capillarity cannot be depended upon to distribute moisture uniformly in the soil. Applications of a small amount of water to the surface of the soil simply wet a shallower depth to its field capacity than a larger amount of water does. In other words, soils in the field cannot be partially wetted, but must be wholly so or not at all.

The losses of moisture which have been stored in the soil are caused by extraction by the roots of plants and by evaporation directly from the surface of the soil. Our experiments show that the amount of water used in transpiration comprises a predominant part of the total losses from the soil, at least under California conditions. The loss of moisture by evaporation is confined to relatively shallow depths of soil. A large portion of the loss is confined to the upper four inches; a much smaller amount is lost from the next four inches. Moisture below the upper eight inches of soil was lost at an extremely slow rate.

Incidentally, mechanically stirring the surface-soil in the manner usual in cultivation practices was found to be without effect on the amount of water evaporated or on the distribution of water in the soil. The movement of moisture by capillarity

from moist soil to drier soil has been found to be extremely slow in rate as well as slight in extent. The experimental results indicate that water which passes below the surface-layer of soil of from four to eight inches thick returns to the surface so slowly either by upward movement in the liquid or vapor-phase that it may be said that the evaporation of water into the atmosphere is affected almost entirely through plant-transpiration.

The draft on the soil-moisture supply by plants continues until the resistance to further removal becomes greater than the suction force of the roots. It has been thought that extraction of moisture will continue until about half the water stored in the soil is utilized. The 1.84 ratio obtained by dividing the moisture-equivalent by the wilting-coefficient as suggested by Briggs and Shantz has been found not to hold for all soils. The moisture-equivalent cannot safely be used as a basis to calculate the amount of water in the soil when plants wilt because a constant ratio does not exist between these two moisture percentages.

We have found some sandy soils that actually contain more available moisture than some clays. An examination of more than 60 soils showed that the readily available water varied from about one-quarter to three-quarters of the moisture-equivalent. These differences did not depend upon the soil classification, that is, whether it was a clay, a loam, or a sand.

No constant relations were found between the residual moisture-content of the soil at permanent wilting, the permanent wilting-percentage, and the absorption of water-vapor over distilled water, 3.3 per cent, 10 per cent, and 44 per cent sulphuric-acid solutions in vacuum-dessicators under controlled conditions of temperature for a period of seven days. This procedure is the one usually followed in most laboratories. There is no simpler way, as far as we know, of determining the amount of readily available moisture in a soil than by growing a plant on the soil and finding the permanent wilting-percentage.

Soil moisture seems to be available with equal facility to plants between the limits of field capacity and about to the permanent wilting-percentage. In our experiments extraction of moisture and the plants were not affected until the soil-moisture content was reduced very close to the permanent wilting-percentage. The slope of the typical curve representing the vapor-pressure of water in the soil in relation to the moisture-content suggests the probability of these experimental results.

Plants grown in containers were wilted under widely differing climatic conditions in experiments extending over a period of six years. The permanent wilting-percentage seems to be determined by the soil and not by the plant. The wilting of plants is controlled by the soil-moisture conditions and not by atmospheric evaporating-conditions and the permanent wilting-percentage of the soil is fixed by the soil regardless of how quickly or how slowly wilting may be reached. Permanent wilting-percentages obtained with small seedling annual plants grown in small containers agreed with those actually found in the same kind of soil with permanently rooted plants in the field.

Studies of the vapor-pressures, rates of drying, freezing-point depressions, and seed absorption on many soils and with plants in solutions of known osmotic values indicate that the magnitude of the forces resisting the removal of water by the plant roots at permanent wilting are considerably greater than that of four atmospheres obtained by Shull by means of the seed-absorption method.

University of California,
Davis, California

THE RELATION OF HYDROGRAPHS OF RUNOFF TO SIZE AND CHARACTER OF DRAINAGE-BASINS

LeRoy K. Sherman

In a previous paper entitled "Stream-flow from rainfall by unit method" (Eng. News-Record, April 7, 1932), the writer defined a "unit graph" as the hydrograph of runoff from a given area, due to a one-inch runoff-depth applied in one day or in any other convenient unit of time. A procedure for deriving the unit graph from observed rainfall- and runoff-records was presented. After the unit graph has been derived a runoff-record for the given area, for any rain or series of rains, may be computed by a simple summation process. Figure 1, from the aforesaid paper, graphically illustrates the summation process and it will not be described further here.

The derivation of a unit graph requires a careful and intelligent analysis of the data. After this graph has been determined for the original area then the unit graph for any other similar basin, regardless of size, may be quickly found. It is the chief purpose of this paper to show how these unit graphs for similar basins may be computed from the original graph.

Figure 2 shows four different drainage-basins, together with some of their physical characteristics. They vary in size from 510 to 5,000 square miles, but are plotted with scales so as to give about the same sized figures. This is for the purpose of facilitating comparison of form and water-course systems rather than area. Note that the Port Jervis Basin, with headwaters in the Catskill mountains, has steep slopes in the Delaware River and valley sides. The slopes of the Oakford and Taylorville basins, in central Illinois, are flat and the slope of the Big Muddy River in the Plumfield basin of southern Illinois is very flat.

Figure 3 shows the unit graphs for each of the four basins illustrated on Figure 2. The peaks of these unit graphs, as well as the peaks of the graphs to follow, do not represent the maximum flow for the basins. The maximum rate of flow, however, can be determined from these unit graphs. Data for these four original unit-graphs were derived from isolated 24-hour rainfall-records of the United States Weather Bureau and the corresponding average daily rates of stream-flow recorded in the Water-Supply Papers of the United States Geological Survey, in cooperation with the states of New York and Illinois.

Figure 4 shows a number of unit graphs for different areas all similar in physical character to the Port Jervis Basin of the upper Delaware River. Figures 5, 6, and 7 are also unit graphs for areas of from 100 to 3,000 square miles, each area being similar respectively to the Oakford, Taylorville, or Plumfield basins. We thus present 23 unit graphs derived from the four originals. By interpolation they cover

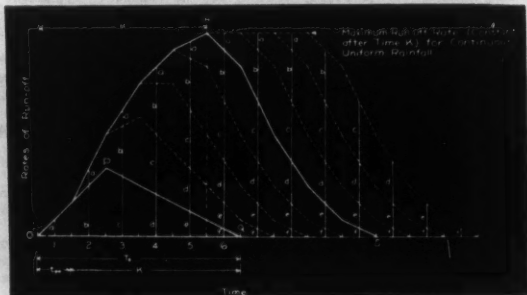


Fig. 1--Diagram of runoffs for continuous rain (based on a graph OPQ due to a unit-time rain)

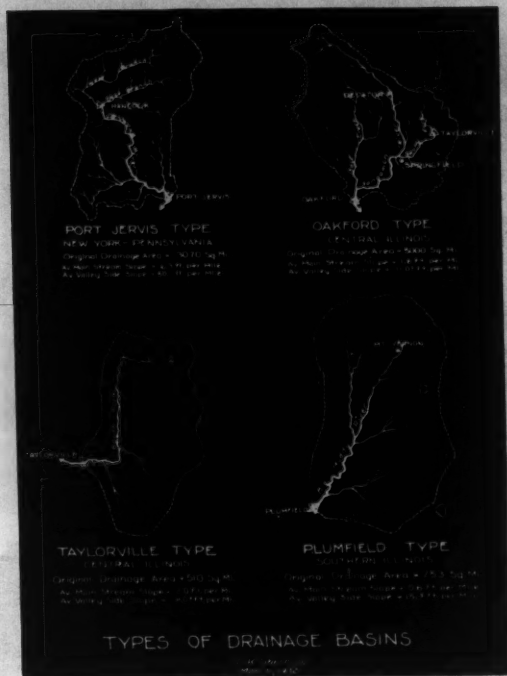


Fig. 2

the entire range between 100 and 3,000 miles or more for each of the four types of basins.

The process of deriving a graph for any sized area similar to the original basin is based upon the principle that the dimensions of similar areas vary as the square roots of the areas. In other words, any ordinate or abscissa of area x is equal to the corresponding ordinate or abscissa of area A multiplied by $\sqrt{x/A}$. Referring to Figure 3 and the original unit graph for the Taylorville Basin of 510 square miles, let us find the ordinate and abscissa corresponding to day 3 of the original graph for a similar area of 100 square miles. From Figure 3 the original ordinate is 3,250 c.f.s. Multiplying 3,250 by $\sqrt{100/510}$ or 0.443 gives 1,440 c.f.s. Multiplying 3 by 0.443 gives 1.33. These two figures locate one point on a graph for one-inch runoff-depth of water over 100 square miles but with a duration of rain of only 0.443 day. (A graph of this type has been presented by the Committee on Floods of the Boston Society of Civil Engineers; see J. Boston Soc. Civ. Eng., Sep. 1930, p. 392.) The desired unit graph, however, is for one-inch runoff applied in one day. Multiplying 1,440 by 0.443 gives 637 c.f.s. as the ordinate at 1.33 days for 0.443 inch of water applied in 0.443 day on a Taylorville type area of 100 square miles. Such a graph corresponds, in principle, to graph OPQ of Figure 1. The graph for a one-day rain is found by the summation process. The following example gives in detail the procedure for computing Taylorville type 100 square miles, as shown on Figure 6, from the original graph for 510 miles shown on Figure 3.

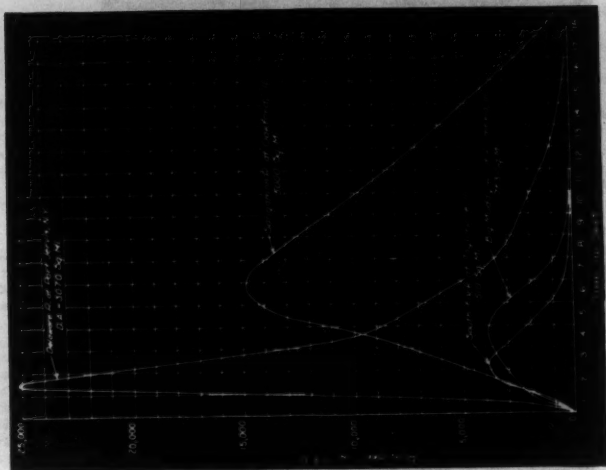


Fig. 3--Unit graphs of rainfall for 24 hours giving one-inch depth of runoff in each case

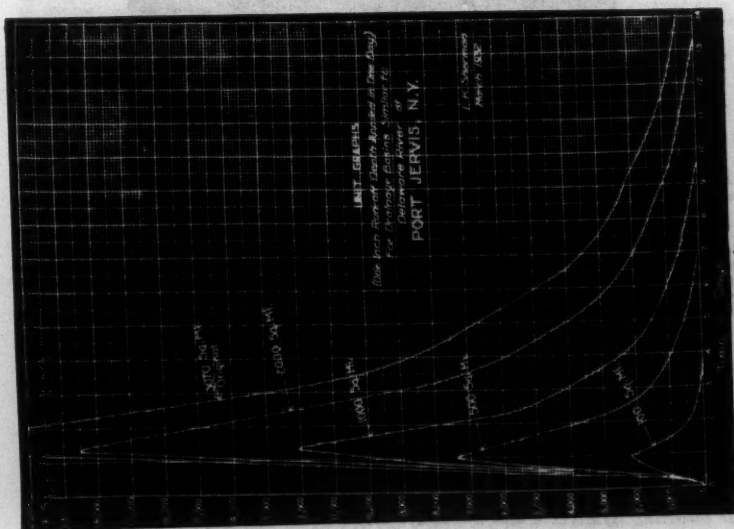


Fig. 4

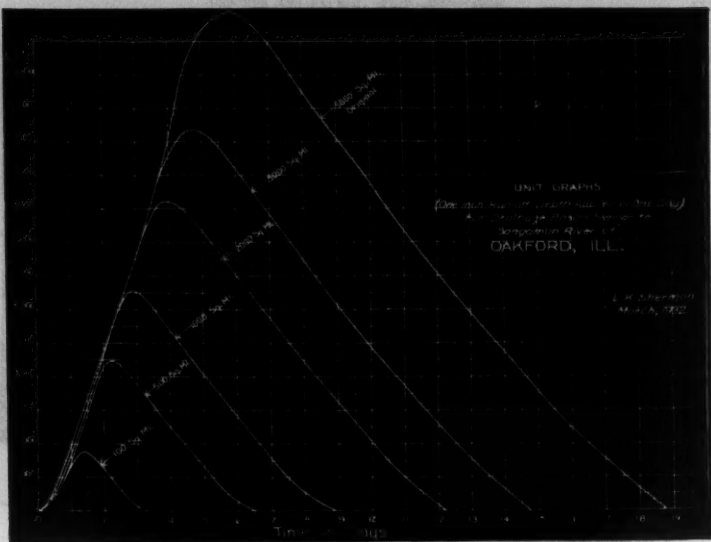


Fig. 6

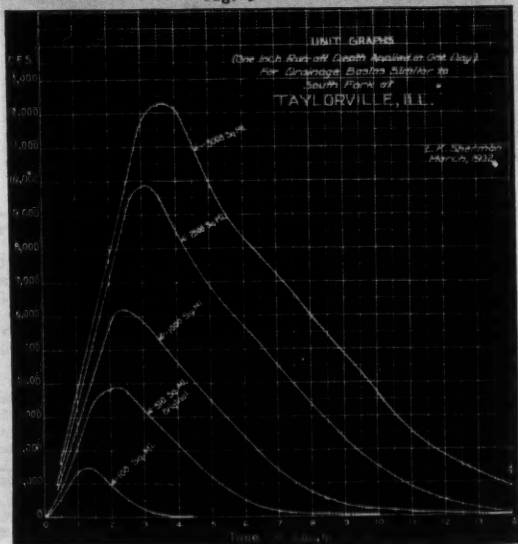


Fig. 6

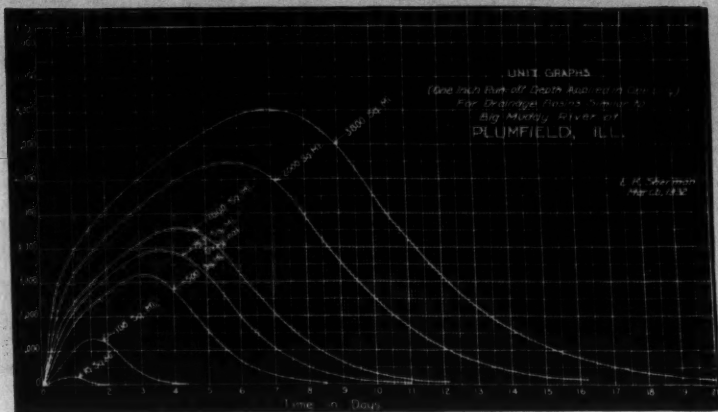


Fig. 7

Specimen computation unit graph 100 square miles, Taylorville type

Original data area A 510 sq.miles (Fig.2)		Computation unit area x = 100 square miles				
(1)	(2)	(3) =	(4) =	(5)	(6)	(7) =
Day	Soaling	(1) $\times \sqrt{x/A}$	(2) $\times (x/A)$	[Note (d)]	[Note (f)]	(4) + (5) + (6)
Day	c.f.s.	Day	c.f.s.	c.f.s.	c.f.s.	c.f.s.
0.0	0	0.0000	0	...	...	0
0.5	1,000	0.2215	196	...	...	196
1.0	2,000	0.443	392	0	...	392
1.5	3,500	0.66	686	196	...	882
2.0	3,840	0.89	752	392	0	1,144
2.5	3,750	1.11	736	686	52	1,474
3.0	3,250	1.33	637	752	103	1,492
3.5	2,750	1.55	539	736	181	1,456
4.0	2,200	1.77	348	637	198	1,183
4.5	1,700	1.99	332	539	194	1,065
5.0	1,200	2.22	235	348	168	751
5.5	800	2.44	157	332	142	631
6.0	500	2.66	98	235	92	425
6.5	300	2.88	59	157	88	304
7.0	200	3.10	39	98	62	199
7.5	150	3.32	29	59	41	129
8.0	100	3.54	19	39	26	84
8.5	80	3.77	15	29	15	59
9.0	50	3.99	10	19	10	39
9.5	40	4.21	8	15	7	30
10.0	30	4.43	6	10	5	21
			...	8	2	10
			...	6	3	9
			...	...	2	2
			...	...	1	1
Total.....						11,978
Check (one inch-mile = 26.85 c.f.s. days): 11,978 $\times$ 0.2215/26.85 = 99 inch-miles vs. 100 inch-miles						

The computation of unit graphs, for any sized area, from an original graph, expressed as a rule is as follows:

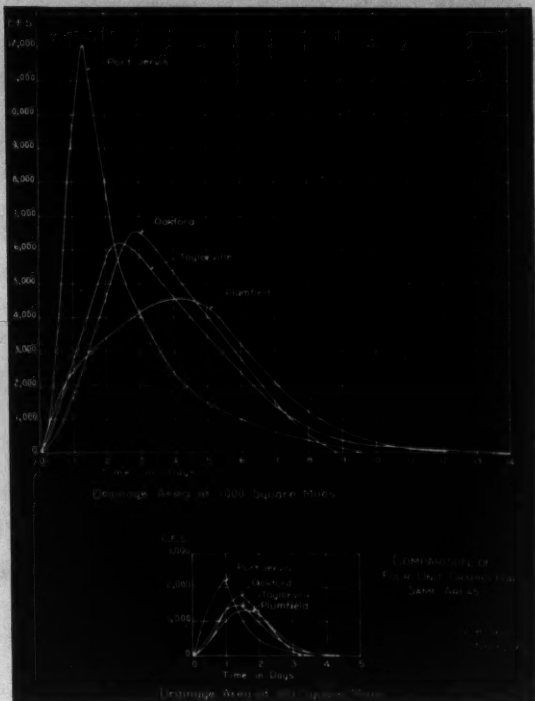


Fig. 8

Rule 1--To compute a unit graph for area x from a known unit graph for area A , proceed as follows when x is smaller than A .

(a) Multiply the scalings for days 1, 2, 3, etc., of graph for area A by $\sqrt{x/A}$, giving column (3) in specimen above.

(b) Multiply the corresponding ordinates of rate of flow of graph for area A by x/A , giving column (4) in specimen above.

(c) Divide 1.0 by $\sqrt{x/A}$ giving an integer n plus a percentage of $\sqrt{x/A}$.

(d) Repeat column (4), starting with 0 c.f.s. on the line for $\sqrt{x/A} \times 1$ in column (3), giving column (5) in the specimen above.

(e) If necessary repeat column (4) again, starting with 0 c.f.s. on the line $\sqrt{x/A} \times 2$, until n [see (c)] such columns are formed.

(f) Multiply each of the figures in column (4) by the percentage of $\sqrt{x/A}$ [see (c)] and start this column with 0 c.f.s. opposite $n\sqrt{x/A}$ of column (3), giving an $(n+1)$ column--column (6) in the specimen above.

(g) Add horizontally the figures in columns (3), (4), ..., $(n+1)$ giving the final column with c.f.s. ordinates corresponding to the time-figures of column (3); this column and column (3) give the ordinates and abscissae for the required unit graph for area x .

(h) Check: Add the last column and multiply this sum by the constant time-interval in column (3), giving the volume of the graph in c.f.s. days; divide the c.f.s. days by 26.85; the result must equal x .

To compute a unit graph for area x from a known unit graph for area A , proceed as follows when x is greater than A .

- (a) Multiply the sealings [column (2)] for days 0, 0.5, 1.0, 1.5, 2.0, 2.5, etc. of graph for area A by $\sqrt{x/A}$, giving column (3).
- (b) Multiply the corresponding ordinates of rate of flow of graph A by x/A , giving column (4).
- (c) Solve $(\sqrt{x/A} - 1)/\sqrt{x/A}$, giving a percentage of $\sqrt{x/A}$.
- (d) Multiply the figures of column (4) by the percentage (c) and start this column with 0 c.f.s. opposite 1.0 of column (3), (or the figure nearest to 1.0) giving column (5).
- (e) Subtract each figure in column (5) from the figure on the same horizontal line in column (4), giving column (6). Columns (3) and (6) give the abscissae (days) and ordinates (c.f.s.) for the required unit graph for area x .
- (f) Check: Add column (6) and multiply this sum by the constant time-interval in column (3), giving the volume of the graph in c.f.s. days; divide the c.f.s. days by 26.86; the result must equal x .

In Figure 8 unit graphs for each of the four basins containing the same drainage-area are superimposed to show the relation due to change in form, topography, and arrangement of water-courses. The Port Jervis type with high peak and relatively short-time base is characteristic of steep slopes and little pondage effect. The Oakford and Plumfield types with flat, rounded crests characterize the flat slopes and high pondage effects typical of most Illinois streams. Each of the four graphs for the same sized drainage-area contains exactly the same number of c.f.s. days, or, expressed in inch-miles, contains 1,000 inch-miles for the large graphs and 100 inch-miles for the smaller graphs.

We will now consider some applications of the unit graph in problems relating to rainfall and runoff.

Runoff as stream-flow is governed by three main factors:

- "A" --Depth of runoff, which is a percentage of, or net depth of rainfall appearing as surface-runoff into the main stream.
- "B" --Distribution of runoff-rates throughout the runoff-period, as indicated by the unit graph.
- "C" --Base-flow or stream-flow derived from ground-water outflow.

Each of these three main factors is the resultant of a number of basic elements. Confining ourselves to areas similar in shape and physical characteristics and limited to about 5,000 square miles and also limiting the precipitation to rainfall, the following tabulation shows the basic elements composing each of the aforesaid three main factors:

"A" Depth of runoff

- 1--Rainfall, intensity, and duration
- 2--Previous rainfall-effect--soil moisture
- 3--Evaporation
- 4--Transpiration
- 5--Infiltration into the ground; soil, character
- 6--Pocket storage or sink-holes
- 7--Temperature
- 8--Vegetation, including secondary pondage effect due to vegetation

"B" Distribution of runoff-rates

- 9--Drainage-area--size
- 10--Drainage-area--shape
- 11--Distribution of water-courses
- 12--Slope of main stream
- 13--Slope of valley sides
- 14--Pondage due to surface or channel obstructions forming natural detention-reservoirs.

"C" Base-flow

- 15--Stream-flow due to outflow of stored ground-water

The unit graph covers factor "B" and reflects all of the runoff-effects due to the physical characteristics of a given drainage-basin (as listed in items 8 to 14 inclusive), excepting soil and seasonal variation of vegetation. The unit graph for any particular basin may be considered as the coefficient of runoff-rates for that area.

The concentration-period for any area is an important factor in any determination of the peak-rate of runoff. It has been defined as the time required for water to travel from the most remote part of the basin to the outlet or distance divided by mean velocity of the stream. The time so derived is generally 20 to 50 per cent less than the time actually observed between the end of a storm and the termination of surface-runoff at the outlet--excepting perhaps small urban areas. This difference is due to the detention-reservoir effect of pondage. A valuable feature of the hydrograph is that it affords a very definite determination of the concentration period without any determination of average velocities. The base of the unit graph (or any hydrograph due to a single storm) minus the time of rainfall is equal to the concentration period. This is illustrated by Figure 1.

The maximum rate of runoff due to a rainfall of uniform rate throughout the concentration-period is equal to the sum of the average daily rates of runoff due to a graph for this rainfall in a unit time of one day. That is, the sum of the daily ordinates of a unit graph multiplied by the rainfall-rate and percentage of runoff. This in turn is equal to the drainage-area in square miles times the runoff-depth for one day times 26.85. It may be expressed thus: Runoff-rate in c.f.s. at concentration-period = $Q = 26.85 R A$, where R = runoff-depth for unit time. The "rational" formula $Q = CIA$ and the Boston Society formula $Q = C_p \sqrt{A} R$, where R = runoff-depth for time of concentration, are both likewise reducible to the form $A = 26.85 R A$. With a fixed rate and percentage of rainfall the peak-runoff at the concentration-period is directly proportional to the area. It is independent of the shape of the unit graph or the physical characteristics of the basin. This simple rule is far from being a formula for peak-rate of runoff. The concentration-period governs the amount of rain that may fall upon a given area.

Peak-flow is not necessarily due to a uniformly distributed rain throughout the concentration-period. It is probably due to a storm distributed in rates throughout the concentration-period in proportion to the ordinates of the unit graph, but applied in reverse order. By means of the unit graph, the peak runoff-rates may be computed and compared for any varying rates of rainfall and with constant or increasing percentages of runoff. It opens up a useful field for investigation.

When a number of unit graphs have been developed to cover a sufficiently complete range of the physical characteristics of different drainage-basins, it will be possible to evaluate factor "B" by direct selection of a unit graph applicable to the required basin. This will enable a close estimate of stream-flow to be made from rainfall data even though no flow-records are available.

This analysis of runoff by the unit-graph method is not complete or perfect. It has just been started. The writer has convinced himself that the procedure is basically sound. He hopes that other hydrologists may be interested to undertake further studies and investigations.

1444 First National Bank Building,
Chicago, Illinois

VELOCITY OF FLOW IN NATURAL STREAMS

H. K. Barrows

Object of paper--The object of this paper is to discuss some of the laws and characteristics of the velocity of flow of natural streams. This will include both a discussion of theory and of some of the common formulae for velocity and also the results of studies of velocity made upon the Delaware River in connection with the recent case of *New Jersey vs. New York* before the United States Supreme Court. A comparison of the results of these velocity studies with velocities obtained by float-measurements through the entire length of this River will also be given, as well as a discussion of such velocities as compared with those of a flood wave passing down the River.

Velocity formulae

Numerous formulae have been developed to express the velocity of flow of streams. Some of these are given below using the following notation:

V = mean velocity at a given cross-section in feet per second

R = hydraulic radius of a given cross-section

= A/P , where A = area and P = wetted perimeter

S = slope of water-surface for a given length of river expressed as a ratio of fall or drop to horizontal distance

Q = AV = discharge in cubic feet per second, or c.f.s.

(1) Chezy-Kutter formula

$V = C\sqrt{RS}$, where C is a coefficient determined from the Kutter formula

$$C = \frac{41.65 + \frac{0.00281}{S} + \frac{1.811}{n}}{1 + \frac{n}{\sqrt{R}} \left(41.65 + \frac{0.00281}{S} \right)}$$

In the Kutter formula, n the coefficient of roughness varies usually between 0.025 and 0.060 for natural stream-channels. It is to be noted that the most important variable in the Kutter formula is this factor n, and for a given hydraulic radius C varies practically inversely as n; S is of slight importance and can usually be ignored. For ordinary river sections R may be taken as closely equal to A/W or D , where W is the width of the stream, and D the mean depth.

(2) Manning formula

$V = \frac{1.486}{n} R^{2/3} S^{1/2}$, where n is the Kutter coefficient of roughness.

Assuming $K = \frac{1.486}{n} \sqrt{S}$, $V = K D^{2/3}$ and $Q = K W D^{5/3}$ if $R = \frac{A}{W}$ as usually assumed.

(3) Soldan's formula

$$V = 25.24 R^{0.744} S^{0.45}$$

This is a formula (see "Über Geschwindigkeitsformeln" by W. Soldan, Berlin, 1931) applying to the Weser River, based upon measurements made between 1902-06 and is similar in form to the Manning formula. Note that $1.486/n$ in the Manning formula would require a value of $n = 0.058$ to accord with Soldan's coefficient of 25.24, keeping in mind, however, that the exponents of R and S in these formulae differ somewhat, so that these coefficients are not exactly comparable.

Velocity of flood-waves

The velocity of a flood-wave, due for illustration to sudden opening of the gates of a reservoir, can not be computed by any of the previous formulae. Sherman (J. Western Soc. Eng., Aug. 1923) suggested for this condition the formula

$$m = (Q_2 - Q_1)/(a_2 - a_1)$$

where m = velocity in feet per second of the moving wave, $(Q_2 - Q_1)$ = the increment of flow, and a_1 and a_2 = the increase in water-area.

Sherman and others have also shown that the maximum possible velocity of the flood-wave is from about 1.5 to 1.7 times the velocity in the risen stream.

Sherman's formula can be conveniently applied graphically by plotting discharge as abscissas and areas of cross-section as ordinates. For a given ΔQ or increase in discharge, and corresponding ΔA , or increase in area, the slope of the curve between the two limits will be the velocity m, and can be scaled off of an accompanying vector-diagram of velocity.

Delaware River investigations

The velocity of flow of Delaware River and time of transit of water from the upper stretches of River were of great importance in the Delaware River case, owing to the very considerable distances between the reservoirs proposed by New York City in the headwaters of the River and points upon the main River where it was essential to maintain a suitable rate of flow.

As a basis for study many cross-sections of the River were therefore taken in the 230-mile stretch between Trenton and Downsville (on the East Branch). Several different observations of water-surface were also taken for different stages of River at the cross-section points, as well as at numerous additional points.

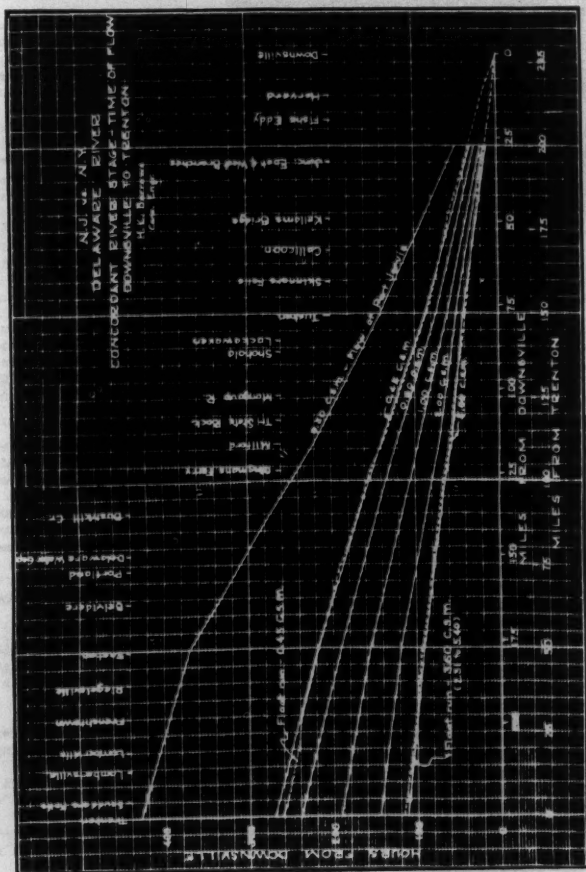


Fig. 1

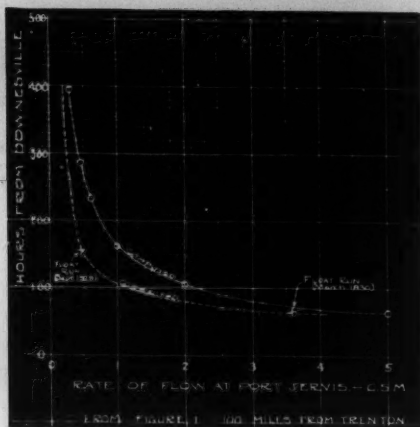


Fig. 2

in c.s.m.: 0.15, 0.30, 0.45, 0.60, 1.00, 2.00, and 5.00. Corresponding unit flows were taken from the relation-curves for each gaging-station and converted to c.f.s. by multiplying by drainage-areas.

Stage-discharge curves were made up for each profile station, based upon the various observations of water-surface, the discharge as measured at gaging-stations and estimated discharge from intermediate areas. These stage-discharge curves were extended to higher stages than those observed, by computations based upon the Manning formula $Q = K W D^{6/3}$, using the hydraulic elements for each station and extended K curves.

By these means concordant profiles of the River were made for each of the seven different unit flows at Port Jervis between 0.15 and 5.00 c.s.m. which showed the river stage at any point corresponding to these various unit flows at Port Jervis.

Computed time of transit--Incident to the compilations of concordant flows, mean velocities were also obtained at each profile point and, based upon these, mean velocities for river sections between adjacent points, thus permitting the approximate time of transit of water to be determined for any one of the various index-stages at Port Jervis. These results, corrected as later explained, are shown in graphical form on Figure 1, which shows time of flow for different concordant stages between Downsview and any point on the River below.

Float-measurements--To check or correct these computed velocities and times, two different series of float-measurements were made (1) September 17-23, 1929, and (2) March 13-22, 1930, the first corresponding to an average stage at Port Jervis of about 0.45 c.s.m. and the second of about 3.6 c.s.m.

In carrying on the float-measurements of September 17-23, 1929, the River was divided into five sections averaging about 50 miles each, with observers working simultaneously in each section. Oranges were used for floats, with good results. The observers used in some cases automobiles to follow up the floats and in certain stretches of the River, canoes and boats. A small percentage of the distance required estimation to complete the runs.

The float-measurements in March 1930 were made in similar manner but at considerably higher stage of River.

Concordant flows and profile--To harmonize these observations concordant profiles based upon various different rates of flow per square mile at an index-station were constructed. This index-station was taken at Port Jervis (D.A. 3070 square miles), approximately midway on the River between Trenton (D.A. = 6,800 square miles) and Downsview (D.A. = 380 square miles).

In determining concordant flows relation-curves between the index-station Port Jervis and each of the other available gaging-stations were determined by plotting the runoff in c.s.m. (cubic feet per second per square mile) at the gaging-station against the runoff at Port Jervis for the same month, thus determining a relation-curve.

Seven assumed index-flows at Port Jervis were taken as follows

Comparison of computed and measured times--The computed times of transit were materially longer than those based upon the float-measurements, due probably to a lack of sufficient cross-sections for computation purposes or perhaps more particularly a lack of them in the quick water sections.

Corrected time-curves at numerous points were made up similar to that shown in Figure 2, assuming the results of the float-run of September 1929 as approximately correct. (In using the results of the float-measurements a coefficient of 0.8 was applied to observed velocities to reduce them to the approximate cross-sectional mean.) At the time these curves were drawn--in December 1929--the second series of float-measurements had not been made and it is of interest to note that when later made they confirmed very well the corrected curve as in Figure 2, as will be noted by the position of the float-run point for 3.6 c.s.m.

The time of transit diagram as corrected and made consistent with the September float-runs is shown upon Figure 1.

Figure 2 is also of interest in showing the great increase in time of transit as river stage becomes low; also the tendency toward a horizontal curve at the higher stages, indicating an approach to an approximately constant time of transit and therefore mean velocity of flow.

Flood-wave velocities, Delaware River--L. K. Sherman made a diagram for the Delaware River similar in form to Figure 1 but based upon flood-wave velocities instead of ordinary flow. He used as a basis for this study the data of cross-sections, hydraulic elements, and concordant flow-relations previously described, determining for six different subdivisions of river curves of discharge-area, from which values of m in his formula for flood-wave velocity were obtained.

His completed diagram of time of transit for the whole length of Delaware River compares as follows with the results shown on Figure 1.

Table 1--Delaware River between Downsview and Trenton--time of flow

Stage in c.s.m. at Pt. Jervis (1)	Time of transit in hours			
	From Figure 1 (ordinary flow) (2)	Sherman assumed flood-wave		
		278 c.f.s. (3)	1,000 c.f.s. (4)	3,000 c.f.s. (5)
0.15	430	260	173	120
0.30	...	150	125	98
0.45	270	122	106	87
0.60	220	108	96	78
1.00	195	84	78	73
2.00	145	68	65	63
5.00	112	53	51	49

By reference to the above Table, it will be noted that at 0.45 c.s.m.--a relatively low flow, for illustration--the time of ordinary flow [column (2)] to pass from the headwaters to Trenton is 270 hours or about 11 days. Flood-waves occurring at this stage of river according to Sherman's formula would pass through this distance in times as shown in column (2) of Table 2.

Table 2--Delaware River--Downsview to Trenton, comparison of flood-wave and ordinary velocities

Flood-wave c.f.s. (1)	Time of transit of flood-wave hours (2)	Discharge at risen stage		Time of transit at risen stage miles per hour (from Fig. 1) (5)	Ratio column (5) to flood-wave velocities (6)
		c.f.s. (3)	c.s.m. (4)		
278	122	1858	0.53	260	2.13
1000	106	2580	0.74	220	2.08
3000	87	4580	1.30	176	2.00

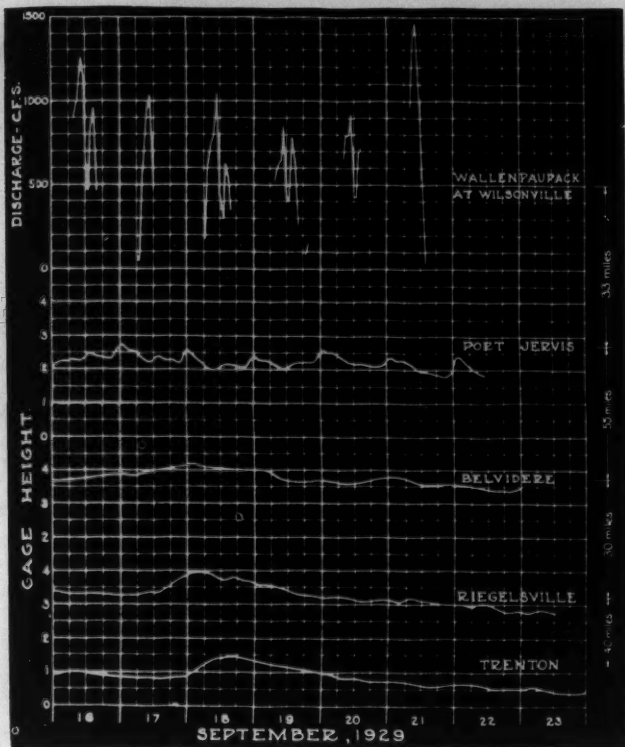


Fig. 3--Delaware River hydrographs, September 16-23, 1929

For a rough comparison of flood-wave velocity with the velocity of the risen stage of river assuming an average drainage-area of 3,500 square miles (the approximate mean of the area at Trenton and at Downsville) and a flow of 1,580 c.f.s. prior to the flood-wave, times of transit for ordinary flow would be as shown in column (5) of Table 2. Comparisons with flood-wave velocities are given in column (6), which shows a flood-wave velocity approximately double the velocity of ordinary flow at the risen stage of river.

The importance of time of transit of water on such a river as the Delaware in respect to the effect of reservoir releases is obvious, and the difficulties of attempting to regulate lower-river flow by reservoirs in the headwaters are evident.

An opportunity is presented on Delaware River to check computed flood-wave velocities. At the Hawley plant of the Pennsylvania Power and Light Company on Wallenpaupack River, due to opening of turbine gates to meet increase in load about 8 a.m. each day, an increase in river-flow downstream of approximately 1,000 c.f.s. occurs in two or three hours--the peak-flow occurring usually about 11 a.m. This causes a daily flood-wave to pass down the Wallenpaupack and Lackawaxen rivers to the Delaware River--a distance of about 10 miles. The effect of this daily flood-wave is very clear at the

Port Jervis gaging-station on the Delaware River, about 33 miles from the Hawley plant--the peak-flow at Port Jervis occurring at about 2 a.m. or about 15 hours after the time of starting of the wave, checking the computed time of flow by Sherman's formula fairly well.

At Belvidere, the next gaging-station on Delaware River, 55 miles below Port Jervis, the effect of the flood-wave appears to some extent at low river stages. It can also be occasionally observed, but much flattened out, at Riegelsville, about 30 miles downstream from Belvidere, and even a slight effect at very low stages is observable at Trenton, 40 miles further downstream.

On Figure 3 are shown hydrographs of Delaware River at these various stations for the period September 16 to 23, 1929, inclusive, and also for Wallenpaupack River. Selecting these days in September for comparison, Tables 3 and 4 were prepared.

Table 3 shows time of flow, etc., between the Hawley plant and Port Jervis on Delaware River--September 17-19, 1929. Time of transit of flood-wave is 14 hours (or about 2.4 m.p.h.r.) but the increment of discharge (low to peak) at Port Jervis averages 650 c.f.s. as compared with 900 c.f.s. at Hawley.

Table 3--Delaware River, Hawley Plant to Port Jervis, time of flow of flood-wave, September 17-19, 1929

Station	Peak - flow					Low - flow					Peak minus low flow c.f.s.
	Day Sep.	Time	Time peak to peak hrs.	Gage-ht.	c.f.s.	Day Sep.	Time	Time low to low hrs.	Gage-ht.	c.f.s.	
Lackawaxen	17	11 am			1030	17	8 am			50	980
	18	11 am			1050	18	8 am			100+	950
	19	11 am			860	19	8 am			100+	760
	Mean				980					80	900
Port Jervis	16	1 am	14	2.60	2500	17	9 pm	13	2.20	1700	800
	18	1 am	14	2.40	2100	18	9 pm	13	2.10	1550	550
	19	1 am	14	2.60	2500	19	10 pm	14	2.30	1900	600
	Mean		14		2370			13		1720	650

Table 4 shows similar data for Port Jervis and Belvidere--September 27, 30, 1929. Time of transit is 37 hours (or about 1.5 m.p.h.r.) and the increment of peak-discharge lowers from 600 c.f.s. at Port Jervis to 200 c.f.s. at Belvidere.

Considering these two periods together it appears that the flood peak-wave of 900 c.f.s. varies as follows as it passes down river: Hawley, 900 c.f.s.; Port Jervis, 600 c.f.s.; and Belvidere, 200 c.f.s. Obviously little or no remaining effect of the flood-wave would appear much below Belvidere.

On Delaware River there are no dams in this entire stretch of river, so that the gradual absorption of the flood-wave is entirely a natural effect. With the usual river conditions any intervening dam would entirely end the passage of a flood-wave.

Table 4--Delaware River, Port Jervis to Belvidere, time of flow of flood-wave, September 27-30, 1929

Station	Peak - flow					Low - flow					Peak minus low flow c.f.s.
	Day Sep.	Time	Time peak to peak hrs.	Gage-hr.	c.f.s.	Day Sep.	Time	Time low to low hrs.	Gage-hr.	c.f.s.	
Port Jervis	27	3 am		2.03	1470	27	12 am		1.50	780	
						28	2 am		1.45	750	690
	28	6 am		1.85	1200	28	11 pm		1.30	600	450
	29	3 am		1.90	1250	29	11 pm		1.30	-	650
	Mean				1300					700	600
Belvidere	28	3 pm	36	3.28	2000	28	3 am		3.6	1700	300
	29	5 pm	36	3.20	1800	29	4 am	26	3.13	1700	
						30	3 am	28	3.10	1600	100
	30	6 pm	39	3.20	1800						200
						Oct. 1	6 am	31	3.10	-	
Mean			37		1870			28		1670	200

Flood-wave velocities based upon hydrograph storm-peaks--Attempts are sometimes made to estimate the velocity of flood-waves by comparing the time of peak discharge at successive gaging-stations upon a river, at time of heavy rainfall. The uncertainty of this method is obvious as it assumes that the peak of discharge is due to water coming down river from the upper reaches of the stream. While this may sometimes occur, the more usual situation is that due to a storm over the whole drainage area resulting in a more or less simultaneous rise of the whole river. The direction of the passage of the storm may also affect the time of passage of flood-peak--especially upon a large river.

Studies of flood-wave velocity based upon hydrograph peaks due to storms, even if made with care, may often therefore give erroneous results.

Form of cross-section--The effective form of cross-section from the hydraulic viewpoint may be shown by the ratio D/D_{max} , where D = mean depth (or practically the hydraulic radius) and D_{max} = maximum depth.

Thus, assuming the point of maximum depth at the middle of the stream:

Cross-section				D/D_{max}
Triangular				0.50
Parabolic				0.667
Rectangular				1.00
Trapezoidal:	Top	Bottom	Depth	
Case (1)	300 ft	200 ft	5 ft	0.83
(2)	400	200	10	0.75
(3)	500	400	10	0.90
(4)	550	400	15	0.87
(5)	600	400	20	0.84

The ratio $D/D_{\max}$ will vary from about 0.75 to 0.90--depending upon the form of trapezoid.

Actual cross-sections on Delaware River show ratios as follows as the average of some 20 typical sections, of wide variation in size and shape:

Delaware River cross-sections

Mean depth feet	Ratio $D/D_{\max}$
2	0.60
5	0.64
10	0.70
15	0.70
20	0.78
25	0.78

This indicates that for the lesser depths the cross-section is effectively parabolic, while at higher stages the section is effectively trapezoidal. Individual cross-sections show much variation--in many cases being effectively triangular, particularly at low stages, or parabolic--while in a few cases ratios over 0.90--approaching a rectangular section--are found.

In general as shown above values of the ratio $D/D_{\max}$ tend to increase with stage (or mean depth).

Delaware River--Hydraulic elements

Based upon the Delaware River work the following appears:

Area and form of cross-section--This included the following approximate range at different stages:

Concordant stage c.s.m.	Area			Width			Mean depth		
	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean
1	5000	6000	3000	830	150	450	10	6	8
5	9000	1000	5000	850	180	500	17	9	12
10	12000	1500	7000	860	170	520	23	11	16

Values of K (in $V = K D^{2/3}$) for concordant stage in c.s.m. 1, 5, and 10 were 0.3, 0.65, and 0.80, respectively.

In general, individual determinates of K appeared to approach the value 1.0 for higher stages.

Values of n (in $K = \frac{1.486}{n} \sqrt{S}$) for the River as a whole averaged as follows for concordant stage in c.s.m. 1, 5, 10, and 20; Uncertain, 0.06, 0.05, and 0.04, respectively.

Detailed values of n for 10 and 20 c.s.m. concordant stages are given in Tables 5 and 6, as well as mean values for approximate 50-mile stretches of river. The results indicate that n tends to increase in the upper stretches of river and to generally diminish in value as river stage increases.

Conclusion

More experimental data are needed to better our knowledge both as to theory and practically, of time and manner of flow in both natural streams and those developed for power use. The Delaware River furnishes an excellent opportunity to study both flood-wave and ordinary flow upon a stream unobstructed by dams.

The general problem is of much importance due to the increasing number of reservoirs being built upon the upper stretches of rivers for power and other use.

Table 5--Delaware River study of stage discharge relation-curves

Miles from Trenton	Eleva- tion	Discharge c.s.m.	S	$\sqrt{S}$	K	$n = \frac{1.486\sqrt{S}}{K}$	Mean values n
0	19.1	10	.000279	.017	0.68	.037	
3.6	24.4	10	.000488	.022	0.90	.028	
7.4	34.2	10	.000614	.025	0.91	.036	
14.2	56.3	10	.000600	.024	0.93	.041	
22.7	83.2	10	.000702	.027	0.90	.040	
30.0	110.3	10	.000566	.024	0.86	.038	.040
33.45	120.6	10	.000423	.021	0.69	.040	
36.6	127.3	10	.000598	.025	1.06	.044	Riegels- ville
40.4	139.6	10	.000593	.025	0.72	.035	
49.6	168.1	10	.000936	.031	0.98	.051	
63.55	237.8	10	.000793	.028	0.81	.038	
73.1	277.6	10	.000558	.024	0.80	.047	Belvi- dere
92.3	334.1	10	.000374	.020	0.78	.052	.053
103.8	356.8	10	.000685	.026	0.60	.046	
111.6	384.7	10	.000870	.030	0.68	.038	
119.95	423.7	10	.001690	.041	1.95	.057	
125.8	475.6	10	.00152	.039	0.82	.023	Port Jervis
130.7	515.0	10	.00154	.039	1.11	.031	
142.0	607.2	10	.00117	.034	1.00	.073	
154.7	685.6	10	.000776	.028	0.72	.071	
165.0	719.7	10	.001070	.033	0.78	.052	.055
181.2	822.2	10	.000800	.028	0.68	.068	
193.3	873.3	10	.000924	.030	0.92	.063	
197.7	894.8	10	.001250	.035	0.95	.072	.057
207.4	958.7	10			0.80	.061	Fish Eddy
						.048	
						.055	
						.065	
							.049

Table 6--Delaware River study of stage discharge relation-curves

Miles from Trenton	Eleva- tion	Discharge c.s.m.	S	$\sqrt{S}$	K	$\frac{n = 1.486\sqrt{S}}{K}$	Mean values n
0.0	23.4	20.0	.000362	.019	0.86	.033	
						.028	
3.6	30.3	20.0	.000448	.021	1.01	.031	
						.028	
7.4	39.3	20.0	.000658	.026	1.08	.036	
						.039	
14.2	62.5	20.0	.000605	.025	0.98	.038	
						.037	
22.7	89.7	20.0	.000876	.026	0.98	.039	.036
						.039	
30.0	115.8	20.0	.000575	.024	0.98	.036	
						.040	
33.45	126.3	20.0	.000504	.022	0.89	.037	
						.031	
36.5	134.4	20.0	.000695	.026	1.05	.037	Riegels- ville
						.048	
40.4	148.7	20.0	.000552	.024	0.81	.044	
						.033	
49.5	175.2	20	.00915	.030	1.08	.041	
						.045	
63.55	243.1	20	.000795	.028	0.98	.042	Belvi- dere
						.044	
73.1	283.2	20	.000563	.024	0.95	.038	
						.038	
92.3	340.3	20	.000337	.018	0.93	.029	.041
						.037	
103.8	360.7	20	.000721	.027	0.72	.055	
						.040	
111.5	390.0	20	.000845	.029	1.00	.043	
						.025	
119.95	427.8	20	.001750	.042	1.70	.037	Port Jervis
						.059	
125.8	481.8	20	.001485	.039	1.05	.055	
						.049	.046
130.7	520.2	20	.00154	.039	1.18	.049	
						.057	
142.0	612.4	20	.00116	.034	1.02	.050	
						.051	
154.7	690.2	20	.000775	.028	1.00	.042	
						.045	
163.0	724.2	20	.001060	.033	0.92	.053	
						.057	
181.2	826.2	20	.000806	.028	0.86	.048	.049
						.042	
193.3	877.7	20	.000880	.030	0.98	.045	Fishs Eddy
						.045	
197.7	898.0	20	.00125	.035	1.00	.052	
						.053	
207.4	982.2	20			0.98		
							.042

The power companies are interested in this matter from the operating standpoint and some practical research in cooperation with them should be carried on in this field, if possible.

Massachusetts Institute of Technology,
Cambridge, Massachusetts

DRAINAGE-BASIN CHARACTERISTICS

Robert E. Horton

Factors descriptive of a drainage-basin as related to its hydrology may be classified broadly as:

(1) Morphologic--These factors depend only on the topography of the land forms of which the drainage-basin is composed and on the form and extent of the stream-system or drainage-net within it.

(2) Soil factors--This group includes factors descriptive of the materials forming the groundwork of the drainage-basin, including all those physical properties involved in the moisture-relations of soils.

(3) Geologic-structural factors--These factors relate to the depths and characteristics of the underlying rocks and the nature of the geologic structures in so far as they are related to ground-water conditions or otherwise to the hydrology of the drainage-basin.

(4) Vegetational factors--These are factors which depend wholly or in part on the vegetation, natural or cultivated, growing within the drainage-basin.

(5) Climatic-hydrologic factors--Climatic factors include: Temperature, humidity, rainfall, and evaporation, but as humidity, rainfall, and evaporation may also be considered as hydrologic, the two groups of factors have been combined. Hydrologic factors relate specially to conditions dependent on the operation of the hydrologic cycle, particularly with reference to runoff and ground-water.

One of the central problems of hydrology is the correlation of the hydrologic characteristics of a drainage-basin with its morphology, soils, and vegetation. The problem is obviously complex. In some cases, as, for example, with reference to geologic structure, it is obviously difficult, if not impossible, to express the characteristics of the drainage-basin in simple, numerical terms. Where definite quantitative factors can be devised, as in the case of soils and morphology, several factors must, in general, be used. In the case of soils, for example, much effort has been directed to the derivation of a one valued factor fully descriptive of the water relations of a single sample of soil. No single factor which is fully adequate for this purpose is thus far available even for a single soil sample and much less for the complex soil system of a drainage-basin.

The most rational procedure seems to be: (1) To determine numerical factors of the various kinds, wherever possible, which are most general in nature; and (2) to confine attention chiefly to those factors for which a pronounced correlation with runoff-phenomena is found to exist.

In the present paper attention will be confined to a few morphologic factors. The object is to express quantitatively the elements of topography of a drainage-basin which affect the operation of the hydrologic cycle, particularly runoff, thus providing a means for a more definite and specific description of drainage-basins. It is not desirable that qualitative descriptions should be omitted--they are often necessary--but rather that they should be supplemented by specific numerical data.

The basis of all the factors described is the topographic maps of the United States Geological Survey for the United States and equivalent maps where they exist for other countries.

It is evident that quantitative terms used should: (1) Be generally acceptable; (2) capable of determination from data usually available and with a minimum amount of labor; and (3) such that the numerical values determined by different workers for the same area will be nearly identical, or at least of the same order.

Starting apparently with Belgrand in his classical work on the Seine, some quantitative morphologic factors for drainage-basins have been developed in continental Europe and are described by Gravelius in his excellent little book *Flusskunde* and in

several papers, by various authors, in *Zeitschrift für Gewässerkunde*. A few factors, particularly with relation to form and general slope of drainage-basins, have been developed in England and in the United States. In general the factor is designated by the name of its author. Most of the factors given have not hitherto been known or in general use in the United States, excepting as to a few European factors and some developed by the author, which were described briefly a few years ago in the *Transactions of the American Society of Civil Engineers* (v. 89, 1926, pp. 1081-1086). All the factors hereafter described have been tested by actual use in the author's practice over a period of years.

Form factor

This is the ratio of the width to the length of the drainage-basin. The length to be used is not necessarily the maximum length but is to be measured from a point on the watershed-line opposite the head of the main stream. For a drainage-basin with a side outlet the length may be less than the width. This factor may be expressed in the form

$$F = M/L^2$$

where M is the drainage-area in square miles and L its length. This factor has been considerably used in connection with maximum flood-discharge formulas. In the case of long, narrow drainage-basins such, for example, as basins occupying synclinal valleys and rift valleys, the form factor is indicative of the flood-regimen of the stream. For drainage-basins of irregular form, especially those with permeable soils, form factor is not a sensitive indicator of hydrologic characteristics.

Compactness

This factor, devised by Gravelius, expresses the ratio of the perimeter of the drainage-basin to that of a circle of equal area, or

$$C = \text{Perimeter}/2\sqrt{\pi M}$$

The minimum value is unity for a circular area. The author has not found this factor to be of special value. Numerically it is the same for two areas of identical form, one with the stream-outlet at the side, the other with the stream-outlet at the end, although the hydrologic characteristics of the two basins will, in general, be markedly different.

Mean elevation

Contour-length method--If contours of a given interval are selected and their length measured by opisometer, then the mean elevation of the drainage-basin is

$$E = \Sigma(lh)/\Sigma l$$

where l is the length and h the elevation of a given contour within the drainage-basin. This method is excellent for small areas and furnishes data which may be used to determine the mean slope of the basin. It is, however, excessively laborious for large areas.

Contour-area method--If the areas between successive pairs of contours of a given contour-interval are measured by planimeter, the mean elevation of the drainage-basin may be expressed by the formula

$$E = \Sigma(a \cdot \frac{h_1 + h_2}{2})/M$$

where a is the area between any pair of contours at elevations h_1 and h_2 , respectively. This method is approximate since the mean elevation of the area a is not precisely $(h_1 + h_2)/2$ unless the contour-lengths at elevations h_1 and h_2 are the same. This method is even more laborious than the contour-length method. It, however, furnishes the basis for a hypsometric curve and also for a precise determination of the mean slope of a drainage-basin, as subsequently described.

Hypsometric curve--If the increments of area between successive pairs of contours have been determined by planimeter, a curve can readily be plotted showing the total area within the drainage-basin lying below any given elevation. The mean ordinate of such a curve represents probably the best possible determination of the mean elevation of the drainage-basin. Such a curve is also useful in interpreting the hydrology of drainage-basins where of high relief. From a hypsometric curve the median elevation, such that 50 per cent of the basin is at lower and 50 per cent at higher elevation, can readily be determined. Median elevation is probably a better indicator of various hydrologic conditions, such as mean temperature and duration of snow-cover, than is the mean elevation. Median elevation is usually slightly below the mean elevation but the difference is usually but a few per cent except in case of some basins of abnormal and high relief. The topographic characteristics of different drainage-basins as regards distribution of relief can readily be compared if hypsometric curves are plotted with elevations expressed in terms of percentage of total relief or difference between the highest and lowest elevations within the basin. In determining a hypsometric curve, fairly wide contour-intervals may in general be used, say, for example, 0.1 of the total relief.

Intersection-method--To avoid the excessive labor involved in measuring contour-lengths or areas intermediate between contours for large areas, a drainage-basin may be subdivided into unit squares by suitably spaced lines and the mean elevation taken as the average of the elevations at the intersections of the cross lines.

Mean drainage-basin profile--If a basin is subdivided as in applying the intersection-method and the mean elevations at line intersections of each line crossing the drainage-basin at right-angles to the axis of the stream are plotted in terms of the distance from the mouth of the stream, a profile will be obtained showing the height of land proceeding upstream. The profile of the main stream plotted on the same diagram furnishes a useful basis for comparison of erosion work performed and remaining to be performed in different parts of the drainage-area. The drainage-basin profile also furnishes the best basis for comparison of elevation with hydrologic characteristics of the drainage-basin proceeding from the source toward the mouth of the stream.

General slope

Hydrologically the declivity of the land surface within a drainage-basin has an important but rather complex relation to infiltration, surface-runoff, soil moisture, and ground-water supply to streams. It is one of the major factors controlling the time of overland flow or concentration of rainfall in stream-channels and is of direct importance in relation to flood-magnitude.

Slope may be considered as of two kinds: (a) General slope, and (b) true, or, as here described, mean slope. General slope may perhaps best be described as the average slope of a surface generated by a line one end of which is fixed at a given point on the stream above which the slope is to be determined, while the other end sweeps along the watershed-line. General slope does not take into account detailed dissection of the drainage-basin by erosion. Methods in common use for determining general slope are various and in general do not give the general slope as above defined.

The Justin method--This method (Justin, Derivation of runoff from rainfall data, Trans. Amer. Soc. Civ. Eng., v. 77, 1914, pp. 346-384) is based on the assumption that if a drainage basin were square, its average inclination would be the difference in vertical height between its highest and lowest points divided by the side of the square. In applying this method to irregular areas the following formula is used

$$s_g = (H_g - H_l) / 6280 \sqrt{M}$$

where H_g and H_l are the elevations of the highest and lowest points in the drainage-basin, respectively, and M is the area of the basin in square miles. It is hardly necessary to point out that this method gives arbitrary results which may depart widely from the true slope of the drainage-basin. It is not correct even for surfaces which are true inclined planes, but gives for such planes different values depending on the slope of the surface. For example, for a smooth surface of slope unity, the formula gives the following results in different cases:

Square area.....	$s_g = 1.00$
Rectangle, length = twice the width.....	$s_g = 1.42$
Rectangle, length = three times the width..	$s_g = 1.734$

For equal square and circular areas with equal slope, the formula gives 12 per cent greater slope for the circular area.

The Landreth method--The following method, utilized by Olin H. Landreth, applies well to a narrow margin of land surrounding a lake. As applied to a lake, the method consists in determining the average elevation of the watershed-line, subdividing this line into segments, each segment being of about the same elevation and at about the same distance d from the lake throughout its length. The approximate area of each subdivision of the drainage-basin is obtained and the mean slope calculated by the formula

$$s_g = [(H_1 - H_0)/d_1] (m_1/M) + [(H_2 - H_0)/d_2] (m_2/M) + \dots$$

where H_0 is the elevation of the lake or large stream used as a datum for each sub-area, and H_1, H_2 , etc., are the average elevations of the watershed-line opposite the different sub-areas, m_1, m_2 , etc. By this method the slope of each sub-area is given a weight proportional to the fractional part of the total area which it represents.

The Frescoln method--This method (Kipp, Hall, and Frescoln, Drainage of Jefferson County, Kansas, U.S.D.A. Bull. 193, 1915, pp. 12-13) is described by its author as follows: The value of $\sqrt{s_g}$ is determined for each simple drainage-basin by first dividing the area into units wherever there is a marked change in the surface-relief, as where a flat area joins a rolling or hilly section, each unit wholly on one side of the main stream. The mean $\sqrt{s_g}$ is found for the course which the water will take from each corner of the unit to the outlet of the whole basin and the average of these values is considered the $\sqrt{s_g}$ for that unit. The value of $\sqrt{s_g}$ for the whole drainage-basin is the mean of the values for the separate units, each weighted according to the area of the unit. Special care is required in dividing the drainage-units for a basin consisting of lands rising quickly from a main channel of small slope, that the large slope of the lands near the outlet may not have undue weight in the final value of $\sqrt{s_g}$.

The Frescoln method is in effect an approximate method of determining the average slope from all points within the drainage-basin to the stream-outlet.

For geometrical figures the mean distance of all points on an area from a point on the perimeter of the area can be determined from the surface integral of the area (Byerly, Integral calculus, pp. 201-209).

For a circular area the mean distance from points within the area to a point on the circumference is $4r/\pi = 1.27323r$.

For a square area, the mean distance from points within the square to one corner of the square, whose side is a , is

$$(a/5) \sqrt{2} + \log_e \tan 3\pi/8$$

An approximate equivalent of Frescoln's method consists in dividing the difference between the mean elevation of the area and the outlet of the stream by the mean distance of points within the area from the outlet. Frescoln's method clearly does not give the mean slope of the ground surface but gives more nearly the average slope along assumed lines of drainage of minimum lengths connecting sub-areas with the outlet.

The object of all the factors for general slope has been in general to furnish a basis for determining the time of flood-concentration. In the author's opinion, general slope is not well adapted to that purpose. Time of concentration involves the true mean slope, so far as overland flow is concerned, and the slope of the streams rather than the slope of the ground surface, where channel flow is involved.

Mean slope

The mean slope between a given pair of contours equals the contour-interval divided by the mean distance between contours. The mean distance between a given pair of contours equals the intermediate area divided by the mean length of the contours. For an area as a whole, if the total length of contours has been determined, the mean slope can be expressed by the formula

$$s_g = D\bar{L}/M$$

where D is the contour interval, $\bar{L}$ is the total length of contours of a given interval, and M is the drainage-area. This formula gives the slope in feet per mile for contour-intervals in feet and contour-lengths and drainage-areas in miles. This method gives good results if the relief is moderate and contours are spaced uniformly. In case of an area a small portion of which has very steep slopes, excessive weight is by this method given to the steep areas and the result cannot be considered as the true average or effective slope of the entire drainage-basin.

With reference to the various methods of determining mean slope it may be noted that some of the earlier topographic maps do not fully reflect erosion-details. In general the greater the length, curvature, or tortuosity of a segment of a contour between two given points, the greater is the slope. Numerical values of slope derived from earlier and less perfect maps are, therefore, likely to be too small, although generally of the right order. A large area may be covered mainly by early maps but if some quadrangles have been resurveyed, a correction-factor can readily be obtained by computing the slope for sample areas from both maps, finding the ratio of the results and multiplying the computed slope for the entire area by this ratio.

Contour-area method--This method seems first to have been suggested by John W. Alford in 1899. The theory is discussed by Gravelius (Flusskunde). The mean distance between successive pairs of contours is determined from measurements of contour-lengths and intermediate areas, as in the contour-area method of finding the mean elevation of a drainage-basin. If a is the area between a successive pair of contours separated by an average distance $\bar{L}$, then for the basin as a whole

$$s_g = \Sigma(ad)/M\bar{L}$$

The slope of each sub-area is thus given a weight proportional to the fraction of the total area which it represents. One advantage of this method is that it furnishes data from which a slope-profile of the drainage-basin can readily be plotted. The two methods thus far described are, however, both excessively laborious where the drainage-basins are large.

The intersection-line method--In order to reduce the labor of computation of slope of large areas the author has utilized the following method. An area the slope of which is to be determined is subdivided into squares of equal size by lines forming the boundaries between adjacent squares. The number of contours crossed by each subdividing line is counted and the lengths of the lines are scaled. Then the average scale-distance $\bar{L}$ between contour-crossings in the subdivision lines is

$$\bar{L}' = \Sigma L/N$$

where N is the number of contours crossed and ΣL is the total length of the subdividing lines. If α is the horizontal angle at which each of two parallel contours crosses an intersection line, then $\bar{L}' \sin \alpha$ is the horizontal distance between the two contours measured normal to the contours. Contours may cross the intersection-lines at all angles from zero to 90° . The mean value of $\sin \alpha$ for angles from 0° to 90° is

$$\int_0^{\pi/2} \sin \alpha d\alpha / (\pi/2) = 2/\pi = 0.6366$$

If D is the contour-interval or difference in elevation in feet, and L is the average normal horizontal distance between contours, then

$$L = 0.6366 \bar{L}'$$

and the mean slope s_g of the area is

$$s_g = D/0.6366(L\delta/N) = 1.571 DN/L\delta$$

In applying this method it is assumed that each contour crossed represents a difference of elevation along the subdivisional line equal to the contour-interval. Of course it may happen that two adjacent contours are at the same elevation and are separated by land only a little higher or lower. On an average, however, the elevations of summits or depressions between equal contours will differ from that of the adjacent contours by an amount equal to one-half the contour-interval and it can readily be seen that the average declivity between a pair of contours of equal elevation is nearly the same as if the contours were separated by the contour-interval D , so that the method gives nearly correct results even where the subdivision lines cross adjoining contours of equal elevation, as in the case of summits and depressions.

By making the subdivision lines sufficiently frequent, the average slope of an area may be determined with whatever degree of accuracy is desired.

This method has been tested by comparison of slope for the same area computed from the measured total lengths of contours, with, in general, good agreement.

Slope components--The slope-components of a drainage-basin may be obtained in the following manner. A system of equal squares is laid out by parallel lines crossing the drainage-basin in north-south and east-west directions, respectively. The number of contour-crossings within the drainage-basin on the north-south lines is counted. The slope in north or south directions is obtained by dividing the product of the number of contour-crossings and the contour-interval by the total length of the north-south lines. The mean slope in east and west directions can be obtained from contour-intervals on the east-west lines in a similar manner. This method gives the average slope in an east or west direction, for example, regardless of the direction. This is an important factor with reference to infiltration and, in the case of east-west slopes it is important in relation to insolation. In the case of north-south slopes, insolation is more nearly related to the net slope. The net slope may be obtained in a similar manner. For example, with reference to the north-south lines, contour-crossings where the slope is toward the south and those where the slope is toward the north are separately counted and the difference used in obtaining the net slope in a north-south direction.

In the case of the net slope, the same result may be obtained by taking the difference in elevations at the north and south ends of the subdivision lines at their points of intersection with the watershed-line and dividing the total difference by the total length of north-south lines.

The resultant average slope and the orientation of the drainage-basin can be obtained from the slope-components by the following formulae.

Resultant slope--Referring to the figure, in the right triangle cod , if oc is taken equal to unity, then

$$ob = \tan \alpha \quad (1)$$

$$ob/od = \tan \beta \quad (2)$$

$$od = \tan \alpha / \tan \beta \quad (3)$$

If the two slope-components α and β are known, it is required to find the resultant slope-angle δ and its azimuth, $s = 180^\circ - \gamma$, where α is taken as the E-W and β as the N-S slope-component and γ is the angle cod (strike-angle) of the projection oc of line bc to the trace cd of the intersection of the sloping plane with a horizontal plane.

Since $oc = 1$, and ce is perpendicular to cd

$$ce = \sin \gamma \quad (4)$$

$$ce/od = \sin \delta = (\sin \gamma / \tan \alpha) \tan \beta \quad (5)$$

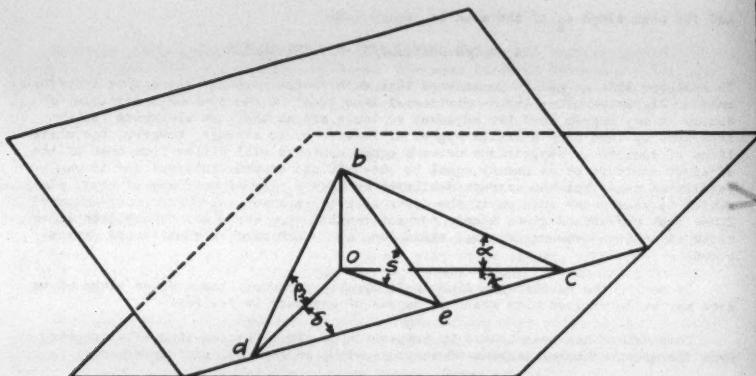


Fig. 1--Relation of resultant slope to slope-components

But $(\delta + \gamma) = 90^\circ$, $\sin \delta = \cos \gamma$, and from (5)

$$\cos \gamma / \sin \gamma = \cot \gamma = \tan \beta / \tan \alpha \quad (6)$$

But $ob/oe = \tan s = \tan \alpha / \sin \gamma$ (from (1) and (4)) (7)

By trigonometry

$$\sin \gamma = 1 / \sqrt{1 + \cot^2 \gamma} = \tan \alpha / \sqrt{\tan^2 \alpha + \tan^2 \beta} \quad (8)$$

and from (7)

$$\tan s = \sqrt{\tan^2 \alpha + \tan^2 \beta} \quad (9)$$

and from (6)

$$\cot \gamma = \tan \beta / \tan \alpha \text{ and } z = 180^\circ - \gamma$$

which determines the slope and azimuth of the line of dip of the plane.

Orders of streams

In European practice the main stream is designated as of the first order, larger tributaries of the second order, and so on down, the highest order being the finger-tip tributaries which have no branches. The author prefers the converse procedure, tributaries which have no branches being designated as of the first order, streams which receive only first-order tributaries are of the second order, larger branches which receive only first- and second-order tributaries are designated third-order streams, and so on, the main stream being always of the highest order and the order increasing with the number of successive bifurcations of its tributaries. To determine the order of a stream-system it is always necessary to have available maps showing the ultimate or finger-tip tributaries.

Bifurcation-ratio--It is evident that the number of tributaries of any given order in a drainage-basin increases in a geometrical progression as the order number of the main stream increases. Treated as a geometrical series of ratio r , the sum of the series or the whole number of streams in a basin would be

$$N = (r^0 - 1) / (r - 1)$$

where o is the order of the main stream. Also if N_1 is the number of tributaries of the first order

$$r = \frac{N-1}{N_1}$$

This may be called the bifurcation-ratio. For a number of drainage-basins for which the bifurcation-ratio r has been determined it has been found to be nearly constant for tributaries of different orders, although it varies for different basins. It appears to be an important physiographic characteristic of the drainage-basin. It indicates the complexity and completeness of drainage or the degree of dissection of the drainage-basin, on the one hand, and on the other, it furnishes a simple basis of determining the lengths of streams of different orders and the total length of streams within the drainage-basin. Much further study of this factor is, however, needed before its value as a hydrologic index of a drainage-basin can be fully determined.

Belgrand's ratio--Belgrand utilized the average drainage-area per stream within a given drainage-basin as a hydrologic index for the basin. The number of streams of a drainage-basin equals the number of stream-sources or stream-terminals. If N_s is the number of streams of all classes, Belgrand's ratio equals

$$K_n = M/N_s$$

Drainage-density

Drainage-density defines the length of streams per unit of drainage-area, or

$$D_d = \Sigma \ell / M$$

where $\Sigma \ell$ is the total length of streams within the drainage-basin of order M . This factor seems to have been first suggested by Neumann in 1900 (Zeits. fur Gew.). Drainage-density is an excellent indicator of the permeability of the surface of a drainage-basin, its value ranging from 1.5 to 2.0 for steep, impervious areas in regions of high precipitation, down to zero or nearly zero for basins sufficiently permeable so that all the rainfall ordinarily is taken into the soil through infiltration. The reciprocal of the drainage-density is the average distance between streams and one-half the reciprocal of drainage-density is the average horizontal distance between streams and appurtenant watershed-lines, measured at right-angles to the streams. Drainage-density is, therefore, closely related to the length of overland flow.

Stream-density

This is the reciprocal of Belgrand's ratio and is expressed by the formula

$$d_s = N_s / M$$

It is the number of streams per unit of area within the drainage-basin. While similar in form to drainage-density, it does not have the same simple and direct hydrologic significance.

Penck's ratio--Penck suggested the use of the average distance between stream-junctions as a measure of stream-density. It is the ratio obtained by dividing the total length of the stream-channels in the drainage-basin by the number of stream-junctions or bifurcations. Apparently, however, the lengths of the first-order tributaries are not intended to be included and a considerably higher result will be obtained if the first-order tributaries are included than if they are omitted in the calculation. If first-order tributaries are omitted, then Penck's ratio is the average length of the segments into which stream-channels are subdivided by the confluence of tributaries. If J is the number of stream-junctions (that is, the number of streams minus one), then Penck's ratio is $\Sigma \ell / J$.

Interesting graphical methods of deriving and illustrating drainage-density, by means of which the drainage-density in different parts of the area may readily be shown graphically on a map, have been devised by Henkel-Bottcher and by Zuerken (Gravelius, Flusskunde).

Average fall and slope of streams

In compiling morphologic data of a drainage-basin from a topographic map, the length of each stream or tributary should be scaled or measured by opisometer and the result recorded in a proper column in a table, together with the elevation at the source and at the mouth. Data for tributaries of different orders should be separately recorded and summated. From these data the average fall, f_a , and the average slope, S_o , of the streams, can be calculated for all the streams in the drainage-basin or for those of each order separately. The formulas are

$$f_a = \Sigma f/N \text{ and } S_o = \Sigma f/\Sigma L$$

where, for a particular stream, f = the elevation at the source minus the elevation at the mouth. The average fall increases with the order of the stream, since no minor tributary can have a total fall equal to that of the main stream. The average slope is, however, greater as a rule for minor tributaries than for those of higher order. The average slope of the tributaries is useful in estimating the effect of stream-channel storage and the length of time required for flood-waves to traverse the stream-channels.

Slope-ratio and tangent-ratio--Slope-ratio is the ratio of the average slope of ground surface to the average slope of stream-channels or, as a formula,

$$r_s = s_g/s_o$$

The value of this ratio is never less than unity, as will appear a little later in connection with overland flow. The tangent-ratio $r_t = \tan s_g/\tan s_o$ is preferable to the simple slope-ratios r_s , as this quantity is used in computing the length of overland flow.

For slopes less than 30° the tangents of angles are so nearly proportional to the angles that they may be approximately expressed by the formula $\tan \theta = 0.168 \theta$ and for angles less than 30° the slope-ratio may be used in place of the tangent-ratio where the latter is required, without serious error.

Direction and length of overland flow

The distance which water must travel overland before reaching definite stream-channels is of great importance hydrologically, especially in relation to flood-intensities from small areas. It also bears a close relation to the general regimen and hydrology of a drainage-basin since the greater the length of overland flow, the greater, in general, is the infiltration and the less the direct surface-runoff.

Referring to Figure 2-A, consider an idealized stream valley as consisting, between its lateral divides, of two intersecting inclined planes, the trace of each of their intersection being the course of the stream. If oa , Figure 2-A, is a horizontal line on one side slope, then ab is the direction of overland flow. In Figure 2-B, if $a'b'$ is the projection of ab on a horizontal plane, then $a'b'$ is the length of overland flow, measured horizontally.

Considering a section of the valley in horizontal plan as shown in Figure 2-C, mn is the projection of the divide at one side of the valley, $a'b$ is the horizontal projection of the course of overland flow, bc is the projection of a portion of the stream, and s_o is the horizontal angle between bc and $a'b$ or the horizontal angle at which overland flow from the point a enters the stream. If $w = a'o$, the horizontal distance from the divide to the stream, and L_o is the horizontal length of overland flow, then

$$L_o = w \operatorname{cosec} s_o \quad (1)$$

The direction of overland flow relative to the stream or the horizontal angle s_o at which overland flow enters the stream can be determined as follows.

Referring to Figure 3, the plane $obdg$ represents a portion of the side slope tributary to the stream at o , the point d being on the watershed-line, the direction of the stream is ao and od is the direction of the resultant slope s_g (dip-slope) of

Therefore $ab/ca = \tan s_0 = ef/oa$

$$\cos s_0 = ef \cot s_g / ef \cot s_0 = \tan s_g / \tan s_0 \quad (2)$$

But, as before, $s_0 = w \operatorname{cosec} s_0$ (1). Combining (1) and (2) and simplifying

$$s_0 = w \tan s_g / \sqrt{\tan^2 s_g - \tan^2 s_0} \quad (3)$$

For areas not too steep the slope-ratio r_s may be substituted for $\tan s_g / \tan s_0$. Also, $w = 1/2D_d$, where D_d is the drainage density. This gives

$$s_0 = 1/(2 D_d \sqrt{1 - r_s^2}) \quad (4)$$

The average length of overland flow in a drainage-basin can be determined by means of formulas (1) and (2) or by formula (3) or (4) when the resultant ground-surface slope, average slope, average stream-channel slope, and drainage-density are given. The derivation of the formulas is predicated on the assumption that the lateral slopes are planes and that the direction of overland flow is in straight lines.

Contours run normal to the lines of slope. If, therefore, lines normal to the contour are drawn on a surface lying intermediate between two stream-channels, they will represent theoretically the lines of overland flow of the water toward the streams. Contours are deflected upward at a stream-channel and are deflected downstream at the divides between two adjacent streams. There is, therefore, a point of inflection somewhere on each contour between a ridge and a stream. For the usual type of natural drainage-basin, the flow-lines are curved toward the stream as they approach the stream-channel.

The exact determination of the average distance which rain must travel overground to reach the stream-channels is impracticable. The water does not always flow parallel with the direction of the slope but, especially on tilled areas, is likely to follow minor depressions or tillage furrows in the ground surface, which on hilly sides are usually at right-angles to the direction of slope. It follows that the total length of overland flow is usually greater than the computed length.

The author believes that the formulas give results of the right order and furnish a basis of correlating differences in hydrologic regimen of different streams with their most important topographic characteristics--slope and drainage-density.

Referring again to formula (1) it will readily be seen that the smaller the tangent-ratio or the greater the lateral slope relative to the stream-slope, the larger will be the angle s_0 . In other words, for steep valley slopes, overland flow tends to enter the stream at right-angles, while for flat areas the angle of inflow of surface-runoff becomes more acute as the channel-slope approaches equality with the ground-slope.

The development of tributaries on lateral slopes of a main stream-valley follows closely the lines of overland flow. Maps of drainage-patterns show in general that parallel tributaries entering the main stream nearly at right-angles are characteristic of steep, serrated hillside slopes, and that tributaries enter larger streams at more and more acute angles as the surface relief decreases.

Application of data--Space does not permit presentation of morphologic factors which have been worked out for many drainage-basins in eastern United States. The following tabulation, from data computed by Glenna B. Holmes (Report on regulation of floods of Onondaga Creek, New York, to the Intercepting Sewer Board of the City of Syracuse, New York), serves to illustrate the nature of the results, the manner in which given factors vary for different streams, and the degree of correlation between the morphologic factors, particularly slope and drainage-density, and maximum flood-discharge.

Physiographic factors for several streams in New York State

Items	Onondaga Creek, Syracuse	West Canada Creek, Hinckley	Little Tona- wanda Creek, Linden	Rondout Creek, Lackawack	Six Mile Creek, Ithaca
Elevation, from - to...	370-1800	1160-3500	1060-1700	630-2900	420-1800
Area of basin, sq. mi..	108.0	374.0	22.6	102.2	84.4
Drainage-density.....	1.14	1.65	1.13	1.03	2.20
Slope of streams, ft/mi	132.5	73.3	114.7	201.7	151.7
Slope of land, ft/mi...	445.	522.	381.	955.	562.
Slope-ratio, r_s	0.297	0.140	0.301	0.216	0.270
Horizontal angle.....	72° 40'	82° 00'	72° 30'	77° 30'	74° 20'
Average distance be- tween streams, mile...	0.877	0.606	0.885	0.970	0.454
Distance, divide to streams, mile.....	0.438	0.303	0.442	0.485	0.227
Average distance over- land flow, mile.....	0.460	0.306	0.464	0.497	0.236
Flood c.f.s.....	6000.	39000.	2500.	14000.	8980.
Date.....	Mar.13,1920	Apr.21,1869	May 10,1910	Nov.9,1913	June 21,1905
Sec.-ft. per sq. mi....	55.6	104.6	113.5	140.	195.2
Reference.....	S.I.S.B.	E.R.,1913, p.402	W.S.P.No. 544,p.74	N.Y.S.E., 1924,p.305	W.S.P.No. 162,p.4

References in tables: S.I.S.B. = Syracuse Intercepting Sewer Board; E.R. = Engineering Record; W.S.P. = Water-Supply Paper, U.S. Geological Survey; and N.Y.S.E. = New York State Engineer.

Voorheesville, New York

THE 1929 FLOODS ON EASTERN NORTH CAROLINA STREAMS

Thorndike Saville

North Carolina has a land area of 48,740 square miles. Of this about seven-eighths is situated east of the Blue Ridge Mountains. The streams draining this large area fall into two groups: (1) Those rising in the Blue Ridge Mountains and thence flowing in a southeasterly direction through the Piedmont Plateau into South Carolina; and (2) those rising in the Piedmont region and flowing southeasterly across the Piedmont and Coastal Plain regions, finally discharging into the Atlantic Ocean or into the North Carolina sounds bordering that Ocean. The three principal streams of this latter class are the Cape Fear River (D.A. = 8,500 square miles), the Neuse River (D.A. = 4,450 square miles), and the Tar River (D.A. = 3,075 square miles). This study is concerned principally with a description of certain hydrological characteristics of the floods occurring on the Cape Fear and Neuse rivers in September and October 1929.

The Cape Fear and Neuse rivers occupy adjacent drainage-basins, and have their origin in the Piedmont Plateau in North Carolina (see Fig. 2) a few miles south of the Virginia border. Both flow in a general southeast direction and have their entire drainage-basins in North Carolina. The Cape Fear crosses the "fall line" into the Coastal Plain a short distance above Fayetteville. The Neuse crosses the "fall line" near Smithfield.

No reliable records of stream-flow on these rivers exist prior to 1922. The United States Weather Bureau has maintained a number of river-stage reporting-stations on the lower portion of these rivers for a considerable period, but only at the Fayetteville station has it been possible to rate the section and make estimates of flow prior to 1922.

Since 1922 the North Carolina Department of Conservation and Development has been active in stimulating the establishment of standard gaging-stations on these two rivers and their principal tributaries. The Army Engineers also established a number of stations on the rivers in 1927 and 1928, which are now being financed from other sources.

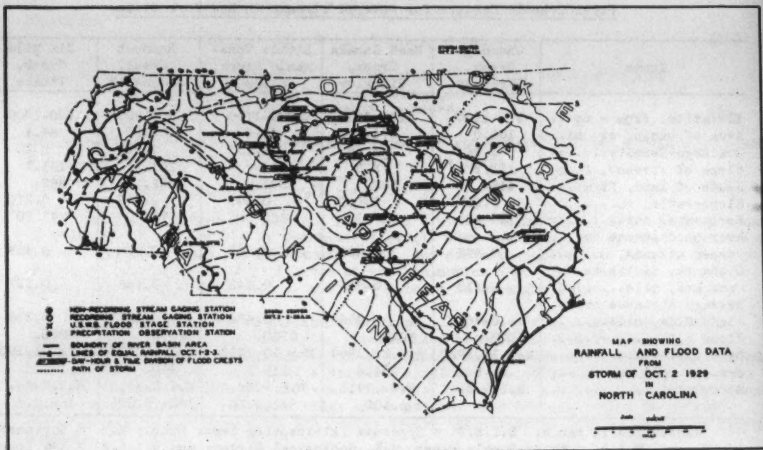


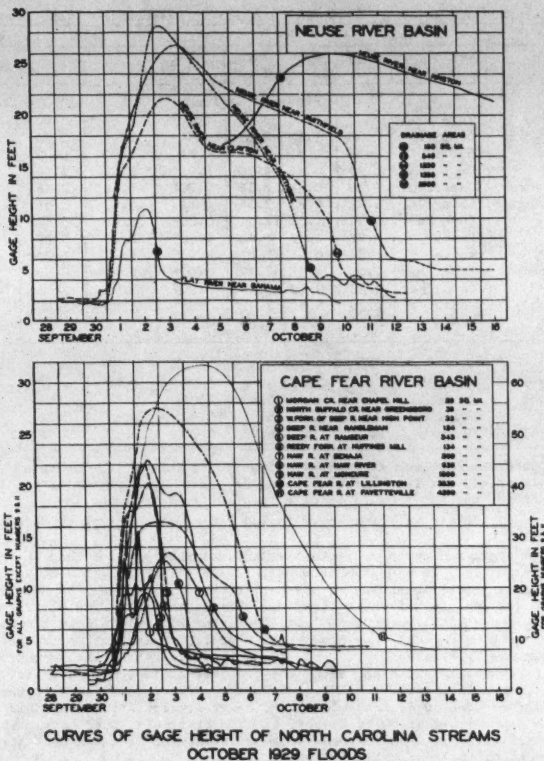
Fig. 1

Some of the stations on the headwater-streams were not in operation until late in 1928, and hence the 1929 floods afforded the best opportunity thus far experienced to obtain data on the flood-characteristics of these two rivers. All of the gaging-stations (shown on Fig. 2) on these two streams are operated by the United States Geological Survey in cooperation with the North Carolina Department of Conservation and Development. Cooperation has been received by the latter organization from the cities of Greensboro, Burlington, High Point, Raleigh, and Durham in the installation and operation of gaging-stations on certain of the headwater-streams. All data in this paper are compiled from official records of the United States Geological Survey, except as noted.

Conditions producing floods

The greatest flood of record on the Cape Fear (at Fayetteville) occurred in August 1908. The greatest on the Neuse (at Smithfield) prior to 1929 occurred in July 1919. These floods were due to only moderately intense but unusually prolonged rainfall. In neither case was the storm due to the movement of a pronounced low-pressure area across the country or to passage of a West Indian hurricane. In 1908 there was a three-day rainfall of from 12 to 15 inches over areas from 500 to 3,000 square miles. In the 1919 storm the rain lasted for a week, with varying intensity, but totaled less than 10 inches. These floods represent runoff from long-continued but only moderately intense rains.

Floods of maximum or nearly maximum proportions on the Cape Fear and Neuse rivers are most frequently caused by rainfall consequent upon the passage of a West Indian hurricane a few days after general rains due to a normal low-pressure area have pretty well exhausted the water-holding capacity of the ground. It is not necessary that these preliminary rains should have produced flood-stages in the streams, although when that is the case the eventual flood will be greater than would otherwise be the case. The great floods of 1916 on the Yadkin and Catawba rivers (the greatest of record) were due to this sequence of events, as were also the large floods on the Cape Fear and Neuse rivers in 1928 and 1929. Although the 1908 flood on the Cape Fear at Fayetteville remains the greatest of record, the 1929 flood was next in order of magnitude and was the greatest of record on the Neuse at Smithfield. The writer believes that, given a long enough period of record, the maximum floods on all streams in North and South Carolina flowing from the Piedmont to the sea will be due to causes similar to those existing in 1928 and 1929. This view is supported by the fact that the two largest floods on the Savannah



River at Augusta, Georgia (October 1929 and August 1928), were due to this cause, the 1908 flood from general rains being the third largest (see foot-note Table 1).

Causes of the 1929 flood

The year 1929 was the year of maximum or next to maximum rainfall at all stations within the Cape Fear and Neuse drainage-basins. The year 1928 had also been well above the average in total rainfall. At the end of August 1929 there was a cumulative excess of from two to four inches of rainfall for the year over most of the two drainage-basins, although rainfall for August was below normal. As a result of this situation, ground-water levels were much higher than is usual in September. Between September 1 and September 26 weak and ill-defined low-pressure areas were responsible for well-distributed rainfall totaling only slightly less than the normal for the entire month. Amount and general distribution of this rainfall are shown in Table 1 for typical portions of the Cape Fear and Neuse drainage-areas. As a result of this precipitation and the generally high ground-water level, the stage was set for production of excessive floods if intense rainfall occurred soon after September 26. [The

Table 1--Rainfall in inches in Cape Fear and Neuse river basins, Sep. 1-Oct. 2, 1929

Location	Drainage-basin	Sep. 1-18	Sep. 22-26	Sep. 1-26	Sep. 30	Oct. 1	Oct. 2	Sep. 30-Oct. 2
I--Piedmont Region								
Asheboro	Cape Fear	2.13	0.73	2.86	0.00 ^a	5.21	3.28	8.49
Chapel Hill	Cape Fear	1.35	1.02	2.37	0.74	5.54	3.34	9.62
Durham	Neuse	0.87	0.37	1.24	0.56	3.00	0.00	3.56
Graham	Cape Fear	3.44	0.66	4.10	0.00 ^a	2.25	3.65	5.90
Greensboro	Cape Fear	1.28	0.88	2.16	0.00 ^a	3.09	2.68	5.89
High Point	Cape Fear	1.72	0.83	2.55	0.62	2.42	1.48	4.62
Moncure	Cape Fear	1.09	1.01	2.10	0.00 ^a	5.95	5.60	11.55
Neuse	Neuse	0.92	0.68	1.60	0.00 ^a	5.20	3.32	8.52
Raleigh	Neuse	1.03	0.94	1.97	2.12 ^b	5.96	1.04	9.12
Randleman	Cape Fear	1.68	0.41	2.09	0.00 ^a	2.90	2.98	5.88
Reidsville	Cape Fear	2.32	0.76	3.08	0.00 ^a	2.65	3.05	5.70
Rougemont	Neuse	1.80	0.82	2.62	0.00 ^a	1.90	3.65	5.65
Roxboro	Neuse	2.70	0.86	3.56	0.00 ^a	1.56	4.60	6.16
II--Coastal Plain Region								
Fayetteville	Cape Fear	....	....	3.45	0.00	2.50	4.16 ^a	6.66
Goldsboro	Neuse	....	....	5.41	0.00	0.87	2.70	3.37
Kinston	Neuse	....	....	5.58	0.00	4.10	0.20	4.30
Smithfield	Neuse	....	....	5.93	0.00	3.57	3.76 ^a	7.33

a) Observations made at 8:00 a.m. instead of late afternoon as at other stations; at all stations marked with an ^a, rain began on the afternoon of September 30, but is recorded in data for 8:00 a.m., October 1.

b) Precipitation is for 24-hour period ending at midnight on date shown.

rainfall in Georgia and parts of South Carolina was much heavier than in North Carolina for this period. From September 25-27, inclusive, there was 9.60 inches at Augusta, Georgia, and 7.40 inches at Greenville, South Carolina. Hence rivers were already in flood when rain from the tropical hurricane occurred on September 30-October 2. For the 34 hours ending 8 a.m. September 27, rainfall on the Savannah River Basin was 8.84 inches. For the 30 hours ending 6 p.m. October 2, the rainfall on this basin was 7.93 inches. The result was a double flood, the second occurring before the first had subsided and being the greatest of record at Augusta, Georgia (Mon. Weath. Rev., Oct. 1929, p. 435).] Such a condition occurred with the passage of a tropical hurricane over North Carolina, heavy precipitation from this cause taking place from September 30 to October 2. The distribution of total precipitation from this storm over the Cape Fear and Neuse river-basins is shown on Figure 2, and is given for specific localities in Table 1.

The West Indian hurricane

On September 25 the weather-map showed a West Indian hurricane developing due west of Miami. Under such conditions the stream-gaging personnel of the United States Geological Survey in North Carolina and the North Carolina Department of Conservation and Development arrange for joint operations to obtain measurements at and near flood-peaks at as many stations as possible, as it is known that if the hurricane moves up the coast severe floods on North Carolina streams will result. This hurricane, however, developed a marked peculiarity. [C. F. Mitchell says "The path of this storm was one of the most erratic and abnormal during the past 50 years. (Tropical Cyclone of September 18-October 4, 1929, Mon. Weath. Rev., Oct. 1929).] Instead of moving inland over the east coast of Florida, and then recurring to the northeast as is the usual course, it recurved to the south, moving very slowly, and finally passed through the Florida Straits on September 27. It was probable then that it would recurve to the north and northeast passing inland across the Gulf Coast. On the morning of September 30 it was evident that it would recurve to the northeast that day. Accordingly, arrangements were made whereby engineers would occupy headwater gaging-stations in eastern North Carolina early on October 1, as it was anticipated the storm would cause flood-producing rainfall on that date, although it was presumed that it would pass out to sea south of North Carolina.

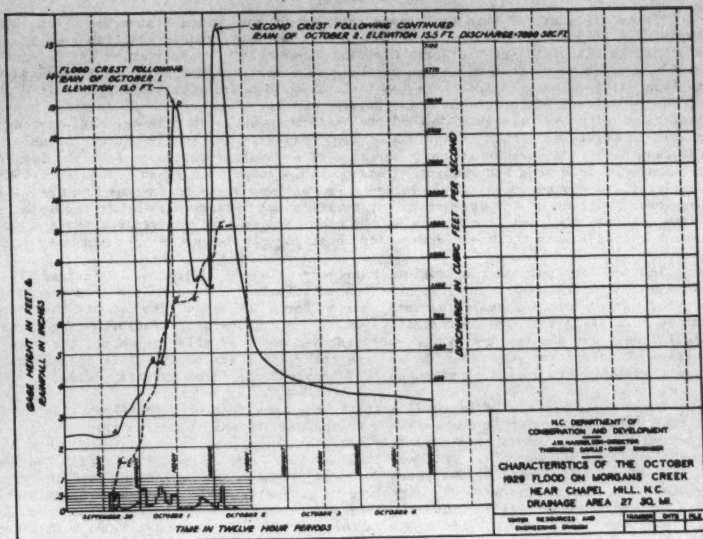


Fig. 3

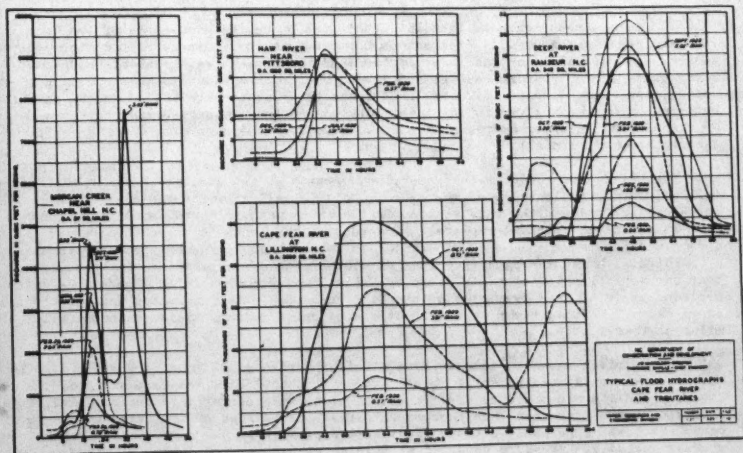


Fig. 4

In an emergency of this sort every engineer of the United States Geological Survey office at Asheville, North Carolina, is in the field, and in addition some from the Chapel Hill office of the North Carolina Department of Conservation and Development. The latter perform no stream-gaging work except under special conditions such as then existed. All engineers in the field keep in touch with the Chapel Hill office of the Department of Conservation and Development which in turn is in constant communication with the Raleigh office of the Weather Bureau. In this way engineers are routed to strategic points in advance of flood-crests. The Weather Bureau is able to forecast with considerable accuracy the time of arrival of flood-peaks on the larger streams, and from such information it was possible to get excellent flood-ratings at nearly all of the gaging-stations in the Cape Fear and Neuse basins, as the crests on the lower portions of the streams do not arrive until several days after the storm has passed, as will be seen from Figure 4. By close cooperation between the three agencies involved a most efficient system for obtaining flood-measurements has been evolved.

The complete path of the tropical hurricane is shown on Figure 1. Instead of passing out to sea on October 1 as had been anticipated, the storm moved in a more northerly direction and passed directly across North Carolina. The path of the storm across this State is shown approximately on Figure 2. The storm followed roughly the "fall line," and the average rate of movement was about 27 miles per hour, the time of passage of the center across North Carolina being about six hours. This is somewhat less than the average rate of movement of a tropical hurricane in this region.

Three phenomena are of especial significance as affecting flood-flows. The first is that total precipitation was heaviest to the west of the storm-center. This is shown on Figure 2, and is true generally over the storm-path in Virginia, North and South Carolina, and Georgia. This would appear to be due in part to the fact that, as stated before, the center of the storm followed roughly the "fall line," and the greater elevation just to the west was effective in producing an increase in precipitation. Also, there existed a well-defined high-pressure area to the west with markedly cool air (see Charles F. Brooks, Sidelights on the hurricane of September 1929, Bull. Amer. Met. Soc., October 1929). The combination of these two factors was sufficient to produce total precipitation over the headwater-streams greater than that over the lower portions of the rivers to the east of the storm-center.

The second phenomenon is that the precipitation on the headwaters of the Cape Fear and Neuse was generally greatest on October 1 (before passage of the storm-center), whereas the rainfall over the lower portions of the streams was greatest on October 2 after passage of the storm-center, and due to the "rain shadow" to the southeast of the center (see Table 1, part II). The result was to delay the arrival of peaks from tributaries of the main river in the lower portions of the drainage-basins to a time nearer the arrival of upstream peaks than would have been the case with a different time distribution of rainfall.

The third phenomenon is the general occurrence of two distinct periods of intense rainfall during the passage of the storm. This is well shown by the data in Table 2 for Raleigh, which is the only station in the storm-path in North Carolina equipped with an automatic rainfall-register. Inasmuch as the center of the storm passed across the Cape Fear and Neuse watersheds in about three hours, and from the location of Raleigh with reference to the upper portion of the drainage-areas, it is believed that the variation in intensity shown by Table 2 and graphically on Figure 2 is quite representative of that over most of the Cape Fear and Neuse watersheds west of the storm-center. It is known to be directly applicable to conditions at Chapel Hill, 25 miles northwest of Raleigh.

The rainfall was most intense from midnight September 30 to noon October 1. The rain then virtually ceased until about 4 p.m. At Chapel Hill the rain stopped, the sky cleared, and the Sun could be seen faintly at intervals during this period. The writer supposed at the time that this phenomenon marked the passage of the "eye" of the hurricane. Such was apparently not the case, as the passage of the center as determined by minimum barometric pressure occurred at Raleigh at 5:30 a.m. and it had passed out of North Carolina by 9 a.m., as shown by Figure 1. The writer then attempted to explain this phenomenon upon the assumption that the midday October Sun produced sufficient rise in temperature of the air to increase its capacity to hold moisture. It is supported by the fact that engineers of the United States Geological Survey at widely

Table 2--Hourly rainfall in inches at Raleigh, North Carolina,
September 30-October 2, 1929

(Rain began 1:59 p.m., September 30, and ended 1:40 p.m.,
October 2--total rainfall 9.12 inches)

Date	1 ^h	2 ^h	3 ^h	4 ^h	5 ^h	6 ^h	7 ^h	8 ^h	9 ^h	10 ^h	11 ^h	12 ^h
September 30	...	...	...	...	...	...	...	...	...	...	...	...
October 1	.63	.64	.10	.14	.17	.40	.72	.66	.23	.19	.36	.34
October 2	.01	.22	.74	.03	.01	T	.02	.01	T	T	(Interval)	
Date	13 ^h	14 ^h	15 ^h	16 ^h	17 ^h	18 ^h	19 ^h	20 ^h	21 ^h	22 ^h	23 ^h	24 ^h
September 30	...	T	.57	.36	.51	.06	.01	.04	.07	.10	.18	.22
October 1	.06	T	.01	T	.05	.05	.15	.36	.32	.25	.12	.11
October 2	T	T	...	...	...	...	...	...	...	...	...	...

separated points in North and South Carolina report a similar phenomenon over practically the same time-interval. Following this cessation, rain again began to fall shortly after 4 p.m., October 1, increasing in intensity until between 8 and 9 p.m., finally stopping entirely early the next morning.

However, at Raleigh the midday increase in temperature was only about one degree, hardly enough to support the hypothesis. It appears from Table 2 and from the plot of that Table on Figure 3 that the rainfall occurred very unevenly throughout the storm, a characteristic of nearly all severe storms in this region. It is concluded that the midday cessation of rainfall has no significance as to time, a similar phenomenon occurring from 6 p.m. to 11 p.m., September 30. The double peak, noted on several hydrographs on Figure 4 is to be regarded as due to purely fortuitous distribution of rainfall-intensity during the storm.

The first rain-period produced the more intense precipitation and a greater total quantity than the second. However, a greater proportion of the second rain ran off quickly into the surface-streams, due to the large amount of water already in the upper portions of the ground. The result was a double peak on all headwater-streams, the second peak being larger than the first. This phenomenon is shown on hydrographs Nos. 1, 2, 3, 4, and 12 on Figure 2. All of these are for stations having less than 150 square miles drainage-area above them. The effect of this, however, is shown on nearly all of the hydrographs of Figure 2 by a break in the curve for rising stage.

Flood on Morgan Creek

The smallest drainage-area for which a hydrograph is available is 27 square miles on Morgan Creek near Chapel Hill. This is shown to an enlarged scale on Figure 3, together with rainfall-diagrams. The latter are from the Raleigh station, 25 miles distant, but observations indicated that the relative intensities are applicable to Chapel Hill. The total amounts may be compared in Tables 1 and 2.

The double peak is clearly evident. Both peaks occur approximately three hours after cessation of the intense rain producing them. Amount of runoff is a function of water-holding capacity of the soil, and hence the second peak is greater than the first. In the latter case the quantity of rain was less, but both the per cent of runoff and total runoff were greater.

The rainfall-runoff relations are estimated as follows:

	Rainfall inches	Runoff inches	Per cent runoff is of rainfall
First period	6.28	1.81	28.8
Second period	<u>3.43</u>	<u>2.51</u>	<u>73.2</u>
Total	9.71	4.32	44.5

Table 3--Miscellaneous data for October 1929 floods in eastern North Carolina

Station	Crest stage feet	Date	Time of cresting	Time-interval between successive stations	Distance between successive stations	Average velocity crest movement		Distance above Fayetteville
						M.P.H.	F.P.S.	
			h m	h	miles			miles
			Cape Fear		System			
West Fork Deep River	11.27	Oct. 2	10 20					144
Deep River, Randleman	20.20		2 13 00	+ 2.66	20	7.52	11.0	122
Deep River, Ramseur	22.12		2 8 40	- 4.33	12	....	....	110
North Buffalo Creek	9.55		2 8 30					116
Reedy Fork Creek	12.65		3 4 40	+20.16	13	0.69	1.01	97
Morgan Creek, Chapel Hill	16.55		2 4 15					75
Haw River near Benafa	13.44		3 8 30					107
Haw River at Haw River	22.45		2 12 35	-19.91	16			89
Haw River at Moncure	33.00		2 24 00 ^A	+11.42	40	3.5		49
Cape Fear at Lillington	27.60		2 22 00	- 2.00	19			30
Cape Fear at Fayetteville	63.40		4 18 30	+44.50	30	0.67	1.0	0
Neuse River System								Above Kinston
Flat River above Bahama	10.77	Oct. 2	14 00					141
Neuse River at Northside	28.60		3 5 30	+15.5	11	0.71	1.04	130
Neuse River near Clayton	21.63		3 9 30	+ 4.0	58	10.6	15.5	72
Neuse River at Smithfield	26.8		3 22 00 ^A	+12.5	13	1.18	1.73	59
Neuse River at Kinston	25.9		10 2 00	+148.0	59	0.399	0.58	0

^a) Time of crest occurrence not known with exactness. Estimate made from plot of Weather Bureau gage-heights.

The response of stream-flow to rainfall is indicated by lettered portions of the hydrographs (Figure 3) of stage and rainfall. The rainfall A B produced the runoff AB. Cessation of rain from B' to C' is reflected in a lowered slope BC. Renewal of rain from C' to D' produces the rising stage CD, and similarly for other designated portions of the curves.

Floods on the Cape Fear Basin

Figure 4 shows hydrographs of gage-heights at various points on the Cape Fear and Neuse basins. Each station is a standard United States Geological Survey gaging-station equipped with water stage register except at Smithfield. This is a Weather Bureau stage-station where readings were taken twice daily and at the peak.

Considering first the Cape Fear hydrographs on Figure 4, attention is called to the lack of sequence which might be expected in time of passage of flood-peaks. Reference should be made to Figure 2, where the location of each station is shown together with time at which the peak occurred. In general it is to be expected that peaks will

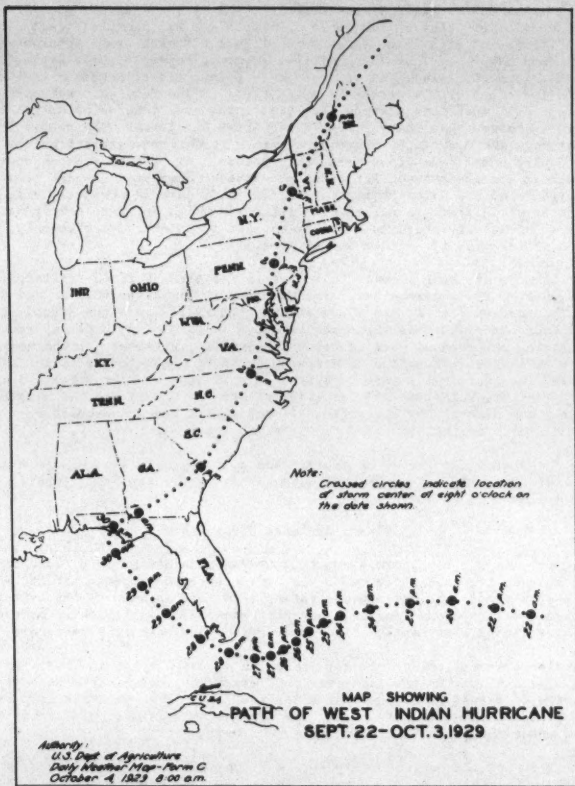


Fig. 5

occur at progressively later times as successive lower stations are reached. Such is not the case in several instances here, as indicated on Figures 2 and 4, and in Table 3. As an example it will be noted that the peak on North Buffalo Creek (D.A. = 36 square miles) occurred two hours earlier than that on West Fork of Deep River (D.A. = 33 square miles). The drainage-areas are nearly the same size, and the general location is similar. The reason for the earlier peak on North Buffalo Creek is explained by the fact that it drains a large part of the City of Greensboro, with paved streets and other factors producing rapid runoff, whereas West Fork of Deep River drains chiefly an agricultural region with sandy soil. By the same token one would expect the total discharge to be greater for North Buffalo Creek, and such is the case, the maximum average 24-hour rate of flow being 1,120 second-feet on this stream as compared with 940 second-feet on West Fork of Deep River. The stage hydrograph of Figure 4 is misleading in this respect, but there is, of course, no proper comparison of discharge at two stations from a comparison of the gage-heights at the stations.

Similarly, one might expect the peak to pass sooner on Deep River near Randleman (D.A. = 124 square miles) than on the same stream at Ramseur (D.A. = 342 square miles)

located 12 miles downstream. On the contrary, the peak at Ramseur occurred four and one-half hours before that at Randleman. This is due to channel-storage above the dams at Coltrane and High Point as shown on Figure 5 (taken from "Water-power investigation of Deep River" by Thorndike Saville, Economic Paper 64, N.C. Dept. Conservation and Development, 1924). At each of these points ridges approach to the River and above each the slope of the stream is quite flat. Below Randleman not only does the River itself fall much more steeply, but the slopes of the three principal tributaries are all much steeper than that of Deep River above Randleman. The result is that channel-storage and low slopes above Randleman retard flood-waters from the 124 square miles tributary until peak-flows from the 219 square miles with steep slopes and little channel-storage between Randleman and Ramseur have passed. The presence of the dams at High Point and Coltrane is of little significance in producing this phenomenon. The reservoir at Coltrane is filled with silt. The High Point reservoir doubtless has a beneficial effect in retarding flood-peaks, but it is one of degree only, and the phenomenon would occur if neither dam existed.

A still more striking anomaly is indicated for time of flood-crests on Haw River at Benaja (D.A. = 209 square miles) and Haw River at Haw River (D.A. = 636 square miles). The maximum peak at the first station (18 miles above the second) occurred nearly 20 hours later than at the second. There is no evident physical reason for this surprising phenomenon, such as topography, soil conditions, or channel-storage. Apparently it must have been due to differences in rainfall-intensity and occurrence not indicated by available rainfall-gages. It will be seen from Figures 3 and 4 that both Reedy Fork Creek (No. 6) and Haw River at Benaja (No. 7) crested much earlier than the maximum peak at Haw River (No. 8), but that a second peak occurred at the latter station due to arrival of peaks from the two upper stations.

All of the stations listed on Table 3 are equipped with water-stage recorders, and the times of arrival of peaks have been carefully checked by officials of the United States Geological Survey.

Floods on Neuse River Basin

The upper diagram of Figure 4 presents hydrographs of the 1929 flood on the Neuse River System. No irregularities as to time of occurrence of peaks are to be noted. The double peak due to the two intense rainfall-periods is seen on the hydrograph for the smallest drainage-areas (No. 12), and this phenomenon is indicated by breaks in the curve for rising stage on the other hydrographs equipped with recorders.

Channel-storage effect is clearly indicated at the Clayton (No. 14) and Smithfield (No. 15) stations by the flattening off of the hydrograph after the peak. The very low rate of travel of flood-crest after the fall line at Smithfield is passed is shown by the Kinston (No. 16) curve, the crest at the latter point occurring about eight days after the storm rainfall.

An analysis of the curves of Figure 4 and the data in Table 3 indicates many incongruities in (a) shapes of hydrographs, (b) time of occurrence of flood-peaks, and (c) rate of travel of flood-crests. Many of these are by no means reproduced even approximately in hydrographs of other floods. It is true that as drainage-areas increase the similarity of flood-hydrographs tends to become more pronounced. For drainage-areas less than 2,000 square miles in the region discussed here, variations in rainfall-distribution and intensity will make anything more than the broadest generalizations from hydrographs extremely liable to error.

University of North Carolina and
North Carolina Department of Conservation and Development,
Chapel Hill, North Carolina

INVESTIGATIONS OF THE FLUCTUATIONS OF WATER-LEVELS IN OBSERVATION-WELLS IN VIRGINIA

R. C. Cady

An automatic water-stage recorder has been maintained on an observation-well in Arlington County, Virginia, about 1-1/2 miles from the United States Weather Bureau,

in Washington, D. C., since June, 1928, but there are a few interruptions in the record. This is a dug well, about 28 feet deep and extends through terrace deposits of gravelly silt or loam. It has not been used for water-supply during the period of record. The recorder was installed by the United States Geological Survey and the record has been given considerable study by O. E. Meinzer, W. W. White, and L. K. Wenzel, all of the Geological Survey. In July, 1931, the study of this well was made a part of a more comprehensive investigation of the ground-water resources of Virginia in cooperation with the State Geological Survey, which was assigned to the writer. The well is essentially of the water-table type, and its hydrograph shows approximately the periods of rainfall-penetration and the relative amounts of recharge in each of these periods. The record is especially instructive because of certain unusual climatic conditions that have existed in the last four years. (See Figure 1.)

The record indicates that none of the rainfall penetrated to the water-table at times when the soil moisture was depleted by plant-growth and evaporation from the soil. There was apparently no recharge in a period of nearly 11 months extending from early in May, 1930, to the end of March, 1931. The soil moisture was severely depleted during the growing season of 1930, and all of the relatively light precipitation during the winter of 1930-31 was required to restore it sufficiently to permit ground-water recharge. In 1928-29 and 1929-30 there were also long periods with no recharge, but the soil moisture was restored earlier in the season, with the result that recharge began about the end of January, 1929, and about the middle of January, 1930. It will be noted that the heavy rainfall in September and October, 1929, apparently failed to produce any recharge, the soil moisture evidently having been severely depleted in the preceding dry months of July and August.

The record shows that the principal ground-water recharge occurs in the winter and spring, after the soil moisture has been restored and before the vegetation of the following season begins to make heavy drafts on it. However, considerable recharge occurs in some summers during periods of heavy rain. In August, 1928, the rainfall amounted to 14.41 inches, which is the highest August rainfall that has ever been recorded at Washington, D. C. In that month the water-level in the well rose about two feet. In the growing season of 1931 there were two periods of recharge--one following heavy rains on the last of May and the first of June, and the other following heavy rains in August.

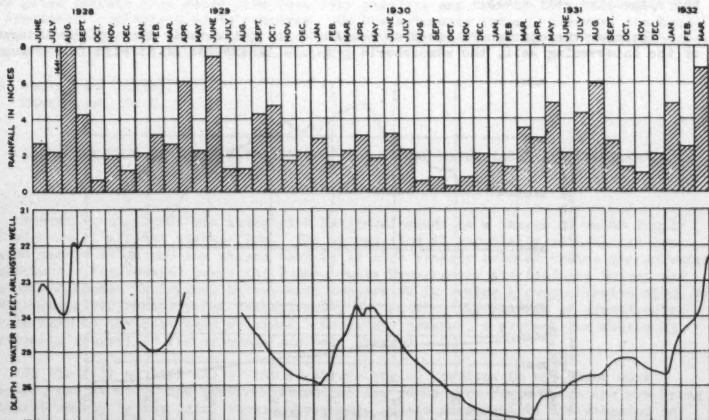


Fig. 1--Hydrograph of observation-well in Arlington County, Virginia, for period since June, 1928, and precipitation-record at United States Weather Bureau, Washington, D. C.

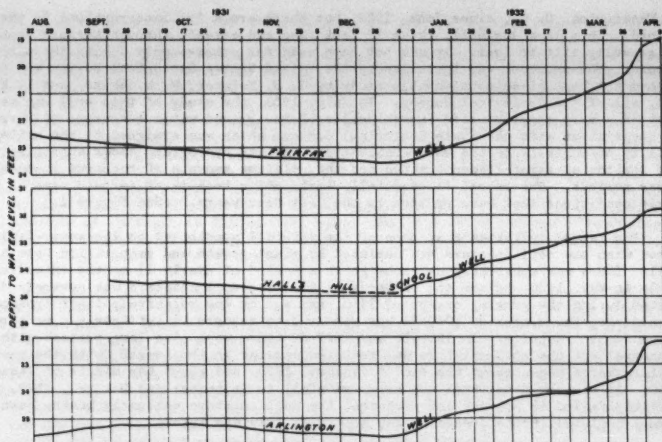


Fig. 2--Hydrographs of three observation-wells in Virginia, near Washington, D.C., since summer of 1931 (The hydrographs of Fairfax and Hall's Hill school wells are based on weekly measurements; that of Arlington well on a continuous record)

Since the middle of last summer weekly measurements have been made on two other unused dug wells in Virginia near Washington, D. C. As shown in Figure 2, the hydrographs of these two wells have the same general character as that of the well that is equipped with an automatic recorder, but they differ from it and from each other in certain details, doubtless on account of differences in the topography and geology of the respective well sites.

Wherever the atmosphere has free access to the water-table through the interstices of the intervening soil, the atmospheric pressure is exerted on it with full force.

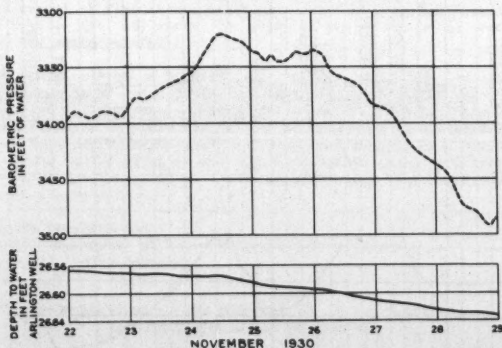


Fig. 3--Barograph at Washington, D. C., and hydrograph of Arlington well, November 22 to 29, 1930, showing slight extent of barometric fluctuations in periods when the soil is dry

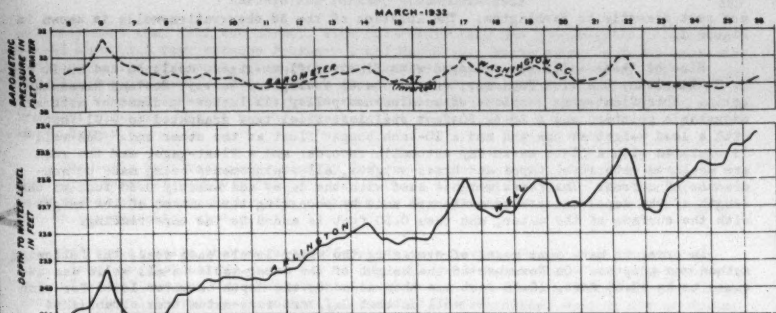


Fig. 4--Barograph at Washington, D. C., and hydrograph of Arlington well, March 5 to 26, 1932, showing fluctuations in water-levels caused by changes in atmospheric pressure and general upward trend caused by recharge

Under such conditions any increase in pressure is exerted about equally upon the water-table outside of the well and upon the water-surface inside of the well, and therefore there are virtually no fluctuations of the water-level due to changes in atmospheric pressure. Figure 3 shows that in the week of November 22 to 29, 1930, at a time when the soil was very dry, notable fluctuations occurred in the atmospheric pressure but only slight resultant fluctuations in the water-level in the observation-well. Figure 4, on the other hand, shows in the period of March 5 to 26, 1932, when the soil was wet, the water-level in the well fluctuated greatly with the changes in atmospheric pressure. The entire record shows that the barometric fluctuations in the hydrograph of the well are always pronounced when the soil is wet and fade out when the soil becomes dry. Evidently when the soil is dry the interstices are open and give the atmosphere free access to the water-table, but when it is wet the interstices are largely filled with water which renders the soil relatively impervious to the air. Obviously a few individual measurements of depth to the water-level in March, 1932, might have given results that would have been very puzzling and that could easily have led to erroneous conclusions as to recharge. On the automatic record, however, the barometric irregularities are clearly seen to be superimposed on an upward trending hydrograph, which unmistakably indicates recharge.

U.S. Geological Survey,
Washington, D. C.

INVESTIGATIONS OF THE FLUCTUATIONS OF THE GROUND-WATER TABLE IN PENNSYLVANIA

S. W. Lohman

Hydraulic engineers are interested in ground-water as a source of water supply and also as it affects stream-flow. The stream-flow is especially valuable at low stages and it is at the low stages that it is most closely related to the ground-water conditions. For several years the Pennsylvania Topographic and Geologic Survey and the United States Geological Survey have cooperated in making a comprehensive study of the ground-water resources of Pennsylvania, but no adequate records of ground-water levels have in the past been obtained. Recently, however, a project for obtaining systematic records in Pennsylvania has been started.

In the fall of 1931 all of the 99 stream-gaging stations in the State were visited, and at 31 of the stations abandoned dug wells were found which are now being measured weekly by the local stream observers. These measurements are recorded on the weekly gage-height cards and sent to Mr. J. W. Mangan, District Engineer, United States Geological Survey, in Harrisburg, who compiles them and sends them to the Washington office. Five other wells are measured by independent observers and the records

are sent directly to Washington. The location of the 36 observation-wells is shown in Figure 1.

Nine of these wells are equipped with Kinnison float-gages, designed and built by H. S. Kinnison, District Engineer, United States Geological Survey, Boston, Massachusetts. This float-gage consists of an aluminum pulley six inches in diameter with an adjustable pointer, and a 25- or 50-foot stainless steel tape graduated to 0.01 foot with a lead weight at one end and a 10-inch copper float at the other end. One well is equipped with a Liets seven-day automatic recorder and a float-gage, and the rest are measured with steel tapes and brass weights, all measurements being made to hundredths of a foot. The brass weights used with the tapes add exactly 0.50 foot to the length of the tape, and measurements are made by observing the contact of the weight with the surface of the water, and then 0.50 foot is added to the tape reading.

In order to have some means of averaging the water-levels each week, the following method was adopted: On November 28 the height of the water-table in all wells was assumed to be 10.00 feet, 10.00 feet was then added to the depth to water-level for each well on that day, and zero-datum thus established for each well from which all subsequent readings were subtracted. That is, if the depth to water-level in a particular well was 27.63 on November 28, the zero-datum would be $27.63 + 10.00$ or 37.63. If the next weekly reading was 25.43, the height of the water-table above the zero-datum would be $37.63 - 25.43$ or 12.20 feet. November 28 was chosen because at that time winter recharge had not yet begun, and it was believed that the water-table would probably never be as much as 10 feet lower in any of the wells than it was on that date. The figures thus obtained are all comparable in magnitude. If a new well is added, no great error is introduced into the averages if on the first date of measurement the new well is assigned a water-level equal to the average obtained from the other observation-wells.

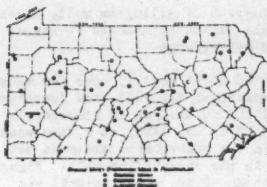


Fig. 1--Map of Pennsylvania showing location of observation-wells

Average water-levels in 36 observation-wells in Pennsylvania (see also Fig. 2)

Nov. 15, 1931	9.96	Jan. 30, 1932	13.06
Nov. 21	10.01	Feb. 6	13.56
Nov. 28	10.00	Feb. 14	13.67
Dec. 6	10.28	Feb. 21	13.23
Dec. 13	10.74	Feb. 28	12.82
Dec. 20	11.36	Mar. 5	12.62
Dec. 27	11.44	Mar. 12	12.22
Jan. 2, 1932	11.97	Mar. 19	12.80
Jan. 9	12.92	Mar. 26	13.87
Jan. 16	12.72	Apr. 2	15.34
Jan. 23	13.14	Apr. 9	14.43

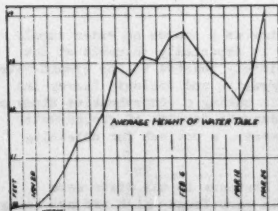


Fig. 2--Average height water-table in Pennsylvania as recorded by 36 observation-wells

The records show that the winter replenishment of the ground-water supply began early in December, 1931. As shown by the records of the United States Weather Bureau, the average precipitation over the State was considerably below normal in October and November, but in December it was 2.85 inches, or nearly normal, and in January it was 4.51 inches, which was well above normal. Moreover, most of the precipitation was in the form of rain rather than snow, and the rain water was not greatly hindered from reaching the water-table by frozen ground. By February 6 the ground-water levels had risen an average of about 3.5 feet. The average precipitation for February was 1.64 inches, which was only

slightly more than half the normal, with the result that the ground-water levels declined about 1.3 feet between February 6 and March 12. Heavy rains in March produced a second period of ground-water recharge, resulting in an average rise of 3.1 feet in the ground-water levels between March 12 and April 2. The total rise from November 28 to April 2 was 5.3 feet. Through the summer the vegetation will make heavy demands on the soil moisture, and it may be expected that there will be a decline in the ground-water levels.

Two wells have been under monthly observation for several years, one of which is now being measured weekly. The records of these two wells indicate that during the past winter the ground-water replenishment in Pennsylvania began much earlier than it did in the preceding winter.

Individual wells show marked differences in behavior, due to topographic location, local precipitation, character of the soil or rock, nature of the vegetation, etc. The well showing the greatest rise is located on a steep hillside in Towanda. The water-level in this well on April 2 stood 23.98 feet higher than it did on November 28. In a number of other wells the water-level has risen from 5 to 14 feet, while in some of the wells it has risen only a few hundredths of a foot; in one well it has actually declined a few hundredths of a foot.

This is but the beginning of the investigation and little has been done other than selecting and equipping the wells, and compiling and averaging the ground-water levels weekly. It is planned to continue the observations for a number of years and to add other wells from time to time. The flow of the streams at low stages is largely ground-water, and the main purpose of this investigation will be to correlate the ground-water runoff with the average ground-water levels, with a view to forecasting low stream-flow conditions. In normal years the minimum runoff in second-foot per square mile in some drainage-areas is as much as eight times the amount in other drainage-systems. Because of such differences in the rate of runoff and because of the differences in behavior of individual wells, it will be necessary to study in detail the geologic and other conditions that influence the individual streams and wells.

U. S. Geological Survey,
Washington, D. C.

HYDRAULIC AND SEDIMENTARY CHARACTERISTICS OF RIVERS

L. G. Straub

Rivers may be distinguished from one another by their hydraulic and sedimentary characteristics. These characterizing elements are so interwoven that it is extremely difficult if not impossible to describe them independently. Suffice it to say that if the bed of an open channel is movable simply by virtue of the energy of the water flowing through the channel, the flow-conditions are much more complex than if the channel is fixed in position. Furthermore, a variation in rate of flow through this channel and consequent variation in transporting capacity results in a continual change in the condition of equilibrium of forces set up between the flowing water and its channel.

A comparison of various rivers with one another indicates that although the hydraulic characteristics, namely, the slope, rate of discharge, variation in discharge, and the like, are very similar for two or more rivers, these rivers may differ greatly from each other. One may have a gently serpentine course with a reasonably uniform depth while another may develop very pronounced shoals and deep pools, providing great difficulty to engineers in their effort to develop a navigable channel. The difference lies largely in the sedimentary characteristics of the rivers, the magnitude of the sedimentary load, and the mechanical composition of the sediment.

The amount of sediment transported in suspension is dependent primarily upon the availability of the finer grades of material. To obtain accurate values of the amount moved in suspension, daily determinations of the sediment concentration in the water at a particular section of the river are indispensable. The quantity of sediment

carried in suspension by a river at any particular time depends upon the quantity of material washed into the stream by surface runoff. A purely theoretical analysis to determine the size and quantity of various grades of sediment transported in suspension is virtually impossible, although direct measurement of the quantity and determination of its mechanical composition are relatively simple procedures.

The bed load of a river, that is, the quantity of material transported along the stream-bottom, is bound to follow more definite laws. Here the difficulty lies in the verification of the laws, direct measurement of the quantity moved along the bed being very uncertain if at all possible. However, a knowledge of the amount of material transported along the bed and the manner in which the quantity is affected by contraction of the channel or steepening of the hydraulic gradient, is of considerable interest and of vital importance in the design of river-control works.

It will now be attempted to summarize as briefly as possible the results of studies to determine relations between flow-conditions and the nature and quantity of the sedimentary load in open channels. Time will not permit giving the mathematical analyses, nor a discussion of the technique of the field or laboratory work.

Distribution of suspended sediment in river cross-section

The material transported in suspension by a river ordinarily varies in concentration with the distance from the water-surface. This variation sometimes appears to be rectilinear, that is, a diagram showing the variation of sediment concentration from the water-surface to a short distance above the stream-bed is often the shape of a trapezoid. Frequently the concentration increases more rapidly as the stream-bottom is approached, thereby giving what might be called curvilinear variation with a rather rapid increase in concentration of sediment near the stream-bottom. As a result of integrating the product of the areas of typical velocity-depth curves and typical vertical suspended sediment-concentration curves, it was found that in a unit width of cross-section the quantity of sediment transported in suspension per second could be determined quite accurately by the equation

$$S = (5/8 \cdot s_{.2d} + 3/8 \cdot s_{.8d}) q \quad (1)$$

where S is the sediment discharge per unit width of stream, $s_{.2d}$ is the sediment concentration at two-tenths the depth of the stream from the water surface, $s_{.8d}$ is the sediment concentration at eight-tenths depth, and q is the water-discharge per unit width of stream. The quantity in parenthesis has been arbitrarily termed the "mean silt content".

Variation in suspended sediment with water-discharge

Notwithstanding the fact that there is a wide variety of circumstances influencing the amount of suspended material carried by a stream, apparently over a long period of time, at least for a great many rivers, there is a reasonably well-defined relation between water discharge and sediment transported in suspension. For the suspended sediment discharge of the Missouri River past Kansas City a theoretical curve represented by the power equation

$$S = 30.4 \times 10^{-11} \times Q^{2.16} \quad (2)$$

was found to apply quite well for time periods of considerable length. This was also found to be true of a number of other rivers, the equation being very different for every river. Here, S is the total silt transported in tons per second and Q is the water-discharge in cubic feet per second. Apparently for very high discharges, in the case of most streams, the amount of sediment transported does not vary as rapidly as an equation of this sort would indicate. (A comparison of the Missouri River at Kansas City is given by the following table for a period of several months.) During the early spring months when the surface of the drainage-area is largely devoid of vegetation, the amount of sediment transported in suspension is relatively larger than during the months of luxuriant growth.

Monthly water-discharge Missouri River, Kansas City		Suspended discharge past Kansas City		
Month	Water-discharge in acre-feet	Month	Measured discharge in tons	Discharge computed by equation in tons
May 8-31, 1929	3,860,000	May 8-31, 1929	19,200,000	24,300,000
June 1929	10,600,000	June 1929	153,000,000	151,000,000
July 1929	5,600,000	July 1929	44,000,000	48,300,000
August 1929	2,180,000	August 1929	6,680,000	6,190,000
September 1929	1,360,000	September 1929	2,040,000	2,200,000
October 1929	1,730,000	October 1929	3,980,000	3,520,000
November 1929	1,900,000	November 1929	4,750,000	4,610,000
December 1929	916,000	December 1929	1,050,000	1,070,000
Total May 8-Dec. 31, 1929	27,946,000	Total 1929	234,680,000	240,990,000
January 1930	898,000	January 1930	2,080,000	1,120,000
February 1930	2,060,000	February 1930	8,510,000	7,150,000
March 1930	3,690,000	March 1930	24,800,000	18,400,000
April 1930	3,310,000	April 1930	16,800,000	14,700,000
May 1930	5,720,000	May 1930	44,200,000	49,200,000
June 1930	4,580,000	June 1930	32,400,000	30,700,000
Total Jan. 1-June 30, 1930	20,258,000	Total 1930	128,790,000	121,270,000
Grand total May 8, 1929-June 30, 1930	48,204,000	Total for entire period of observation	363,470,000	362,260,000

Retention of sediment in suspension

A number of observations on rivers, indicates that the material transported in suspension, particularly in many heavily laden rivers, remains in suspension unless the flow is artificially retarded. (Fig. 1 presents an example of this statement.) Suspended sediment discharge-observations were made for about a month at two cross-sections of the Missouri River, at Kansas City and Waverly respectively, about 80 miles apart. The maximum and minimum suspended loads in the case of these two stations, occur approximately one day apart in almost every instance. Assuming a mean velocity of about three miles an hour, this would be the time required for the silt-laden water to flow from Kansas City to Waverly. Furthermore, although there was considerable variation in the mechanical composition of the suspended sediment during the period of observation, the mechanical composition of the finer grades of sediment gathered at the two stations respectively on successive days, was practically identical.

Nature of suspended sediment

The nature of the suspended sediment as well as the quantity transported at any time is dependent upon various indeterminate factors such as the amount and location of precipitation in the drainage-area, the season of the year and hence the progress of vegetation, the extent and locality of cutting banks, etc. (A graphical presentation of measurements for one day at a particular river section is represented by Fig. 2; this figure and other similar studies permit several important deductions.) The finer material, particularly that classified as silt and clay [diameter of particles smaller than 1/16 millimeter (0.0025 inch)], is distributed fairly uniformly throughout the river section. On the other hand, the amount of coarse material transported in suspension, that is, the material classified as sand [diameter of particles greater than 1/16 millimeter (0.0025 inch)], increases significantly toward the stream-bottom. The percentages of the various grades of material, of course, vary for various rivers. The significant fact is that the finely divided sediments appear to be quite uniformly distributed throughout the river cross-section.

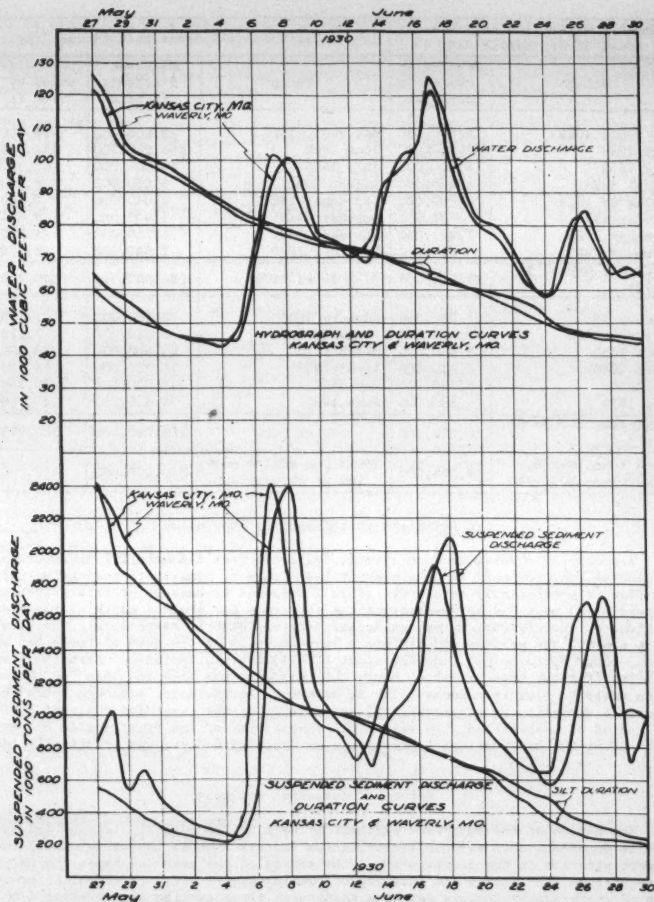


Fig. 1

The season of the year greatly influences the type of sediment carried in suspension. In the winter when the drainage-area is covered with snow, very little surface-flow reaches the river and the suspended material is relatively coarser than during other seasons. This must not be construed to mean that more coarse sediment is transported in suspension, but merely that less fine material finds its way to the river.

Some rivers show a marked difference in the mechanical composition of the material transported in suspension and that moved along the bed; other streams have relatively fine sedimentary beds and steep hydraulic slopes, and therefore, show a less pronounced difference in the nature of suspended and bed loads.

Bed sediment transportation

The movement of sediment along the stream-bed, of course, is greatly influenced by the direction as well as the velocity of flow in the lower part of the river. The channel of an alluvial river is a succession of three characteristic shapes, namely, bends, crossings, and reaches. At bends the water-filaments follow helical paths, the surface-flow being toward the concave shore, the bottom-flow toward the convex shore. This motion is readily explained by the fact that the centrifugal force at bends is greater near the surface than near the stream-bottom, since although the radius of curvature at the stream-bottom is the same as that at the surface, the velocity near the bottom is less because of greater frictional resistance at the bottom.

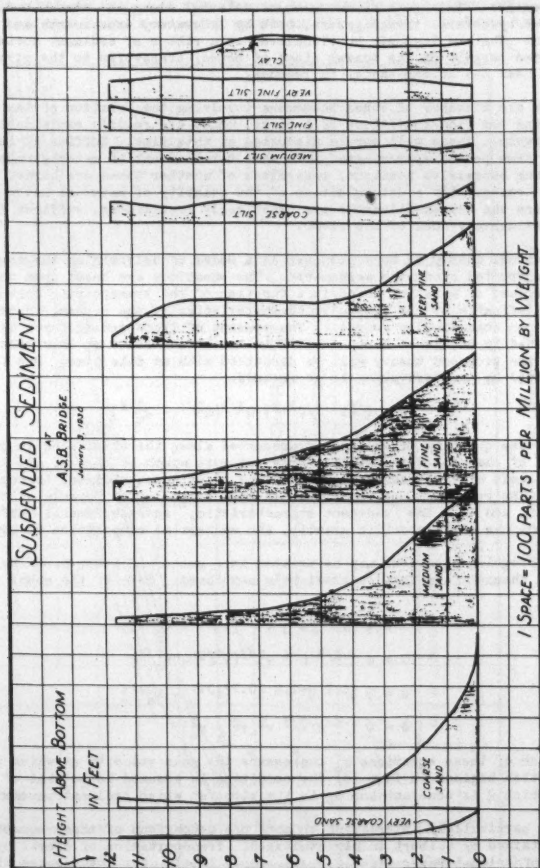


Fig. 2

Crossings are the points of contra-flexure of successive bends and are subject to the formation of shoals, which normally rise with rises in the river stage. In reaches, that is, in straight river stretches, during uniform or falling stages there is a tendency toward double helical flow from the shore toward the center of the stream at the surface and in the reverse direction at the bottom. During rising stages, particularly rapidly rising stages, the flow appears to be from the center of the stream toward the shore at the surface and from the shore toward the center of the stream near the bottom. These helices, of course, are very long, the pitch being many times the breadth of the river.

In consequence of this flow-condition the sediment tends to move along the bed from convex shore to convex shore in the case of bends and in a more or less straight path in reaches. This path of movement of material along the stream-bed has been pointed out by several investigators, both by laboratory experiments and field observations. The bed load may be visualized as a ribbon of sediment moving downstream, concentrated largely on the convex sides of bends, transverse to the river at crossings, and near the stream-center in reaches.

There are a number of other phenomena involving the relation of the sediment-movement and the flow-conditions of a river, which are readily explainable at least quantitatively. These will not be discussed at this time. Suffice it to say that over a long time period approximately the same total amount of material must be transported along successive sections, regardless of whether these are bends, crossings, or reaches. Consequently a determination of the quantity of material moved along a reach, where the stream-filaments are practically rectilinear, suffices for determining the sedimentary load of the river.

A rational theory is here proposed as a means of determining the amount of material transported along the stream-bed. The equations are based upon the hypothesis that the amount of material moved is a function of the transporting force and that the latter is definable by the hydraulic characteristics of the stream, therefore, by a suitable open channel-flow formula. The concept of transporting force is not new; it was described by DuBois as early as 1879 in *Annales des Ponts et Chaussées*. The derivation of the proposed theory will be dispensed with at this time. One form of equation obtained by the derivation is as follows:

$$G = \psi [1.4/c^{1.2}] Q^{3/5} [Q^{3/5} - Q_0^{3/5}] \quad (3)$$

where G is the quantity of sediment transported along the stream-bed in pounds per unit width of channel, Q is the discharge per unit width of channel, Q_0 is the discharge per unit width of channel (for a slope 1) at which sediment transportation begins, c is the roughness coefficient in an open channel-flow formula of the form $v = C R^{2/3} i^{1/2}$, and ψ is the sediment characteristic, an experimental coefficient depending upon the size, specific gravity, and mechanical composition of the sediment.

The foregoing equations may be written in a number of other forms by use of the power open channel-flow formula previously mentioned. Some of the other forms are as follows:

$$G = \psi [1^{1/2}/c^3] v^{3/2} [v^{3/2} - v_0^{3/2}] \quad (4)$$

$$G = \psi Q^{-2/3} c^{-4} v^{7/3} [v^{7/3} - v_0^{7/3}] \quad (5)$$

$$G = \psi Q^{1.2} c^{-1.2} i^{0.7} [i^{0.7} - i_0^{0.7}] \quad (6)$$

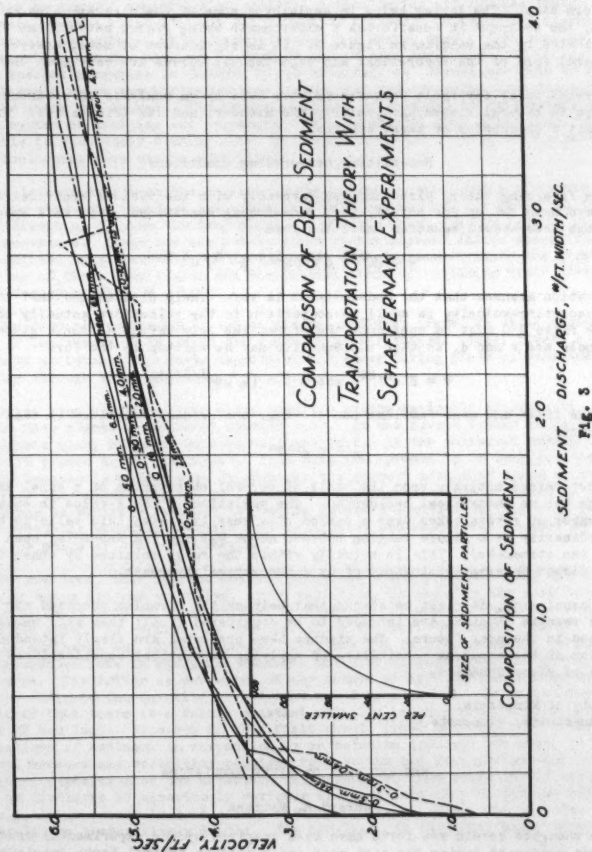
$$G = \psi c^{-4} i^{-2/3} v^2 [v^2 - v_0^2] \quad (7)$$

In each of these equations v_0 represents the mean velocity at which bed sediment transportation begins; in form (6) the condition is assumed to be that of a tilting flume in which Q is constant and i_0 is the slope at which sediment movement begins.

It is particularly interesting to note the comparison of these equations with the results obtained by Gilbert in his studies of "Transportation of debris by running water" (Professional Paper 86, U.S. Geol. Sur., 1914). For the purpose of an approximate comparison of the foregoing equations with Gilbert's statements it will be assumed

that the "critical" or competent transporting discharge, slope, and velocity, respectively, become very small when compared to the actual discharge, slope, and velocity; that is, for example, the comparison will be made on the basis of v_0 approaching zero. Gilbert found from his experiments that "For each combination of discharge, width, and grade of debris the value of capacity is approximately proportional to a power of the excess slope above competent slope (slope at which transportation of sediment begins, i_0). Thus, he found empirically that the amount of sediment transported per unit width varies as $(i - i_0)^n$, n being found to range between 0.93 and 2.37. In the way of comparison when i_0 in equation (6) approaches zero the corresponding value of n is indicated to be 1.4, a value which lies approximately half way between the extremes observed by Gilbert.

Furthermore Gilbert observed that "For each combination of width, slope, and grade of debris, the stream's capacity varies as $[(Q - Q_0)^p]$. He found that p varies



between 0.81 and 1.24. It is again interesting to note that in the rational equation (3) as Q_0 becomes very small relative to Q a value is obtained which corresponds to p approaching 1.20. Again Gilbert states that "If the slope be constant in which case velocity changes with discharge, the capacity varies as the 3.2 power of velocity"; but for very small values of v_0 compared to v , which was the case in most of Gilbert's work, equation (4) indicates the capacity to increase with the third power of the velocity. The proposed theory has been analyzed by other similar comparisons with the experiments of Gilbert, and with the experiments of Schaffernak of Vienna, and also with experiments recently made at the University of Minnesota, all of which compare favorably.

Figure 3 shows a typical comparison with Schaffernak's experiments. In making this comparison the critical transporting force was determined from an analysis of experimental data from various sources, while the values for the sediment characteristic were determined principally from Gilbert's experiments where the sediment was of uniform size. The latter helps in explaining some of the discrepancies in the comparison, the sediment in Schaffernak's experiments being graded between the size limits indicated by the diagram in Figure 3. It is significant to note, however, that the general form of the theoretical and experimental curves are very much the same.

Several other favorable comparisons were made by an analysis of sediment transportation in natural rivers, particularly the Missouri and its tributaries. Time will not permit a discussion of these studies.

Non-silting, non-eroding conditions

The foregoing theory also compares favorably with the various empirical equations which have been set up for non-silting, non-eroding conditions. For this special condition the theoretical equation takes the form

$$v = \left[\left(\frac{g}{Q} \right)^{1/3} c^{4/3} \frac{1}{d^{1/3}} \right] d^{5/9} \quad (8)$$

This equation assumes that the bed-sediment is very finely divided and that the critical transporting-velocity is small in comparison to the velocities actually obtained. Here the ratio g/Q must be constant; therefore, the only variables for a given network of channels are v and d , so that the equation may be written in the form

$$v = K d^{0.56}, \text{ where } K = \left[\left(\frac{g}{Q} \right)^{1/3} c^{4/3} \right] \quad (9)$$

One of the first and most familiar non-silting, non-eroding equations is that of Kennedy, namely

$$v = C d^{0.64} \quad (10)$$

It was determined entirely upon the basis of careful observation of a canal network in India and has no theoretical background. The variation of the K -value in equation (9) for a number of rivers taken over a period of a year indicates this value to be computed ordinarily as a figure ranging between about 0.7 and 1.2 depending upon the nature of the stream-bed. This is actually within the range obtained by other investigators by direct observation instead of by a theoretical approach.

In conclusion, it might be stated that neither the formulas proposed nor the comparative results obtained are intended to be considered final; they will unquestionably be revised in the near future. The studies here presented are simply intended as an indication of the apparent possibility of applying theoretical considerations to the problems of river dynamics.

University of Minnesota,
Minneapolis, Minnesota

NEW THOUGHTS ON RIVER REGULATION

Gerard H. Matthes

The thoughts herein set forth have been inspired by the experimental dredging-operations conducted during the past year and a half in several North American rivers.

They relate to new applications of old and well-established principles of river dynamics. While a description of the experimental work is beyond the scope of this paper, it may be stated that it is concerned with the establishment and maintenance of navigable channels in tidal as well as non-tidal rivers. The methods employed, which here will be referred to collectively as the Ferguson system of river regulation, are aimed chiefly at securing a more complete utilization of the kinetic energy in flowing water than has been attempted hitherto. (Col. Harley B. Ferguson, Corps of Engineers, United States Army, and Division Engineer in charge of river and harbor work along the South Atlantic Coast, is the originator of the new system referred to and is directing the experimental work.) The remarkable success that has attended this experimental work to date indicates that the methods are basically sound and are likely to find wide application.

Establishing and maintaining navigable channels in rivers constitute, primarily, a problem in handling sediment. In the last analysis, it means providing adequate velocities to prevent deposition at critical points during all but the lowest stages. Most rivers possess kinetic energy sufficient to transport not only the mineral debris normally contributed by their watersheds, but vastly more. This surplus energy, until recently, has not been put to work by man to best advantage. In the Ferguson system, special attention is devoted to its utilization. Rivers are made to erode their channels where greater depths are needed, and are prevented from depositing materials where not wanted. The agitation method of dredging is extensively used. The old system of dredging and redredging the same shoals, year after year, without being able to stop their forming anew, is likely to become a thing of the past if the new channel conditions can be stabilized.

Shoals have ever been the engineer's *bête noire* in maintaining navigable channels. The vexatious problems presented by them have absorbed his attention to the extent of diverting it from the deep places in rivers, which now are looming up as of major importance. These are the points where rivers possess excess energy that has been permitted to go unused. The experimental work is demonstrating the great potential value of these deep places and the possibilities of utilizing their excess energy towards deepening shallow places.

Many deep places appear to act as natural sediment traps, in which sediment lodges at low stages to be swept out again at higher stages. Tidal rivers show this process in an intensified form, deposition and scour taking place alternately twice every day through tidal action.

It has been customary, the world over, to create navigable channels by connecting the deep places by means of dredged cuts. It has always seemed to be a logical and economic plan, at least as regards first cost. In the matter of upkeep it has not always proved to be economical. This plan now appears to be open to grave apprehensions because in many rivers it destroys the correct action of these natural sediment traps the moment they are made part of a continuous channel. There is indication that it may be entirely feasible to restore nature's equilibrium, and even improve on it, by providing existing channels with artificial sediment traps located at strategic points, by means of ordinary dredging.

The bed load, that is, the heavier materials which progress along the bottom of a stream by being dragged or rolled, or by saltation, is probably the most troublesome item to be dealt with in river-channel regulation. It appears to be the very item concerning which, as regards the transportation of debris by running water, least is known to engineers and physiographers. Yet, the bed load is primarily responsible for forming obstructions in navigable channels and also in destroying the useful life of reservoirs. The writer is not aware of any method of silt determinations which will reliably indicate the quantity of bed load moved by a stream. He is inclined towards the belief that there is a fairly constant relation between stage or discharge and amount of bed load. Research in this field should prove of considerable value. Determinations of sediment in suspension or in solution are less important in this connection, because any velocities required to keep the bed load moving will automatically prevent deposition of the materials in suspension. The ratio of the latter to stage or discharge is notoriously variable and unsatisfactory of determination. Fortunately, large errors in such determinations appear to affect the problems of channel regulation comparatively little. The bed load, on the other hand, should be known

better than it is, not only as regards quantity and quality of the materials composing it, but also as regards the bottom velocities required for its transportation.

There is great paucity of data pertaining to the character of the materials composing river beds in unconsolidated formations. In so important a river as the Mississippi below Cairo, practically nothing has been known until recently regarding variations in the texture or hardness of the bed formations from point to point, or regarding the effect of such variations as reflected in channel shifting or other forms of instability. On many important streams the only records of borings now available are those obtained in connection with foundation explorations for bridges, dams, and locks.

There is reason to believe that in the study of curvature too much effort has been expended in establishing relations with discharge, width, and fall, and too little in connecting up channel alignment with geological factors.

Probably the greatest stumbling block in providing adequate channels in the past has been cost. Time-honored methods of dredging appear strangely inadequate when a clear conception is obtained of the vast quantities of materials which a river handles unassisted in the course of its annual regime. When it is considered, for instance, that a single Atlantic Coast stream, in its 100-mile tidal reach, transports back and forth with the tides, twice a day, as much as half a million cubic yards of mud and sand, man's efforts in removing from such a channel ten million cubic yards in dredging operations in the course of a year seem truly puny, and the cost involved--a million dollars--almost grotesque. The ideal system of river regulation must reckon yardage in terms of billions, must utilize favorable currents for moving this yardage, and must reduce present-day dredging costs to mere fractions. The astonishing rapidity with which the rivers experimented on appear to yield to the Ferguson system of treatment is such as to render hydraulic laboratory experiments a waste of time by comparison. This is said, not in disparagement of laboratory methods, for the writer is an ardent advocate of the hydraulic laboratory, but to emphasize that in this instance direct experimentation on the full-scale channel is proving eminently satisfactory.

Attention is invited to the need of making more frequent sounding-surveys in rivers undergoing improvement. Surveys undertaken two or more years apart, as is often customary, afford mainly food for conjecture as to what changes take place in the interim, and are hardly worth their cost.

The writer believes that much of practical as well as of theoretical value will come to light as the new system of regulation is placed in operation on other rivers. Due account is being taken of the necessity of considering each river a separate problem calling for individual treatment.

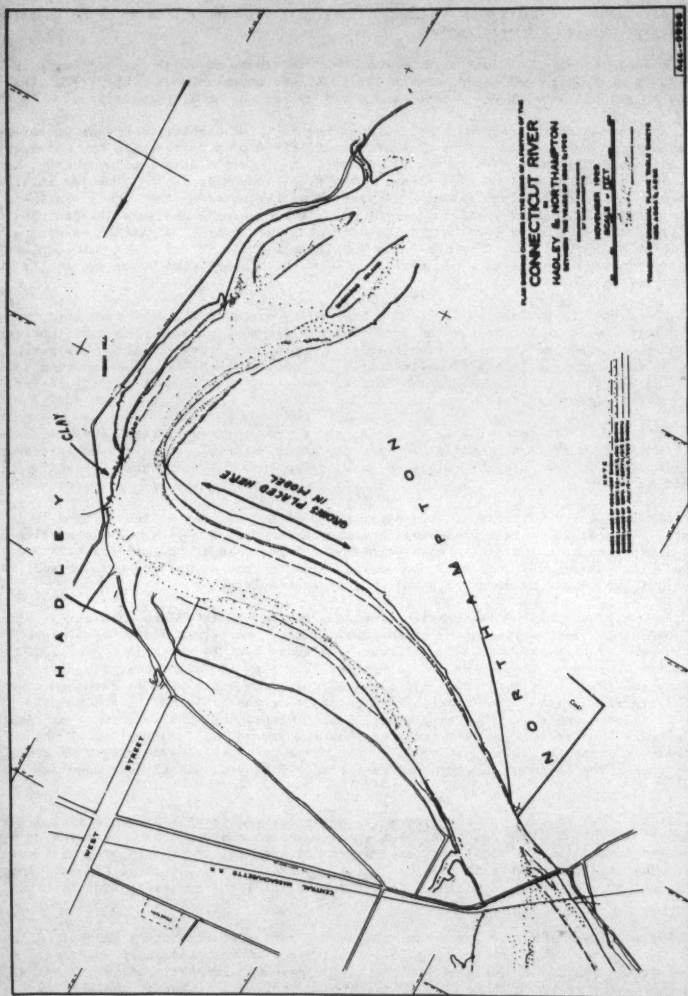
U.S. Geological Survey,
Washington, D. C.

MODEL RESEARCH IN THE RIVER HYDRAULIC LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY

J. B. Drisko

Hydraulic model studies have proved to be of great aid to the engineer, and research along hydraulic lines is essential to progress in this field. To provide for this type of activity, a River Hydraulic Laboratory was started at the Massachusetts Institute of Technology in 1929. Several investigations have been already completed or are being carried on at present.

Erosion below the apron of a proposed spillway was studied on a one-to-sixty scale model. The studies indicated changes in the spillway design which, in the model, reduced the depth of scour below the apron by one-half, and shifted the scour to a portion of the river bed where it would be harmless. The proposed full-size spillway was redesigned as a result of the model work.



same equipment to investigate the effect of varying the bank slopes upon the quantity of seepage through a porous levee.

A scale model of a floating dry-dock, the usefulness of which was seriously impaired by silt which collected beneath the dock, was constructed and operated. The exact source of the silt was located and a remedy for the difficulty devised.

At present there are four thesis researches in the laboratory. One is an investigation of the variation of the discharge-coefficient of a spillway as the water approaches at different angles to the crest and with different depths of approach channel. A second thesis is a model study of the tidal phenomena in the proposed enlarged Cape Cod Canal, with a lock situated in various positions along the canal. Further, a member of the laboratory staff is investigating the pressure- and velocity-distribution in flow over weirs of various heights to determine the physical significance of the coefficient of contraction. The remaining thesis is a study of the transportation of sand by running water, similar to work done by G. K. Gilbert some years ago at the University of California.

The latter investigation is being conducted in a wooden flume 32 feet long, two feet wide, and 15 inches deep. The bottom of the flume is covered with sand, and sand is fed in at the top to replace that carried along by the flowing water. The grain size of the sand used in the flume is nearly uniform, varying from 0.864 mm to 1.130 mm. These sizes pass a 16-mesh screen and are retained on a 20-mesh screen. Later, other sizes of sand will be used.

At present, the apparatus is complete, and a few preliminary runs have been made. The aim of the work is to analyze the various factors affecting the transportation of material, and if possible, to determine some of the laws governing the movement of detritus.

Although the conditions of this experiment are not similar to those found in natural streams, it is felt that investigations in a straight, parallel flume using a flat stream-bed of uniform sand will permit easier analysis of the many factors concerned. An extension of the work, to include straight and curved channels of various cross-section, would be of great value, and is contemplated.

Recently, a study of destructive erosion along the banks of the Connecticut River was completed. Near Northampton, Massachusetts, the Connecticut River flows easterly with a gradual curve to the left, followed by a sharp bend to the right (Fig. 1). Above the sharp bend the depths are fairly uniform; just above the bend the River widens, and there is a deep eddy; and along the bend the outer bank is steep and the depths are very great. The River at this point is in the backwater of the Holyoke Dam, 11 miles downstream. During periods of high water, when the velocities and depths are greatly increased, the river banks are heavily eroded, and the portion of the river in question is shifting laterally. The River is slowly encroaching on a road which runs along the high bank by the sharp bend. This road has already been set back once.

It was felt that the problem presented here--that of preventing or lessening the destructive erosion along the banks of the River--would admit of study by means of a hydraulic model. Such a model was constructed and operated and proved very instructive. The model, representing some two miles of river, had a length of 55 feet along the thread of the stream, a width of from three to six feet, and was formed in fine sand.

The model was distorted, that is, the depths were proportionately greater in the model than in the actual river. Physical limitations of the laboratory governed the choice of the horizontal scale--a scale of 1:200 gave the largest model which space permitted. The vertical scale of 1:50 was chosen to insure motion of the sand in the model, and to minimize the influence of small absolute depths. After a period of operation it was found that this fourfold distortion was too great: The river bed eroded excessively in certain places, causing large riffles which disturbed the flow, and the river banks in the model would not stand at as steep an angle as the distortion required. The model was reshaped to a vertical scale of 1:100, giving a twofold distortion. Results with this model were more satisfactory.

The paucity of data from the actual river regarding the flow-stage relation at Northampton made it necessary to work with rather sweeping assumptions. In general, flood-stages were produced in the model, and the slope was then regulated to produce erosion similar to the erosion in the actual river. Erosion along the bank above the sharp bend in the model was almost entirely lacking. The soil at a corresponding point in the actual river is much finer and more easily scoured than the soil along the sharp bend; hence, erosion in the model, which was made of uniform material throughout, is to be expected first along the sharp bend. After the proper flow-conditions for the model had been determined, various types of correction-works were investigated.

In the model, the flow around the bend had a distinct spiral or horizontal corkscrew character. The surface layers flowed to the outside of the bend, where they were deflected by the bank, and thence flowed diagonally down the bank to the bed of the stream. Erosion is aggravated by the impact of the current on the bank, and by the component of flow down the bank toward the bed of the stream.

With the hope of forcing the current above the bend away from the shore and out into the large pool, directly against the resistant clay bank, a series of groins was placed along the concave bank in the model above the bend. The result was only partially successful. The current was forced over so that it struck the clay bank and the erosion immediately below this point was lessened. Farther downstream, however, the erosion persisted.

Two forms of bank protection were tried in the model, namely, a series of small strips of window screening forced part way into the sand along the eroding bank, and a form of intermittent revetment-- ribs of loose pebbles, which in nature would be loose stone.

The screening functioned much as permeable groins, that is, the velocities close to the bank were reduced and erosion prevented. Screening in the model would correspond to some form of hurdles or metal jetties in nature. One of the chief difficulties would be that of anchoring such jetties on the very steep bank which exists here.

In using the screening, it was found that the inclination of the strips relative to the current was of prime importance. If placed with the lower ends slightly upstream from the top ends, the effect was good. If placed with the lower end downstream from the top end, the screens were of no value, since the corkscrew current flowed nearly parallel to the screens. Strips of expanded metal, having openings about one inch by one-third inch, were not nearly as effective as window screening, which was much finer and offered more resistance to the flowing water.

An intermittent revetment, consisting of "ribs" of loose pebbles was tried in the model and found very satisfactory. In Nature these ribs would be of loose stone and would adapt themselves to any irregularities or changes of the river bank.

Due to present conditions, it is doubtful if anything will be done on the actual river. This is unfortunate, as one of the most necessary and valuable phases of any model investigation is a comparison of the behavior of the model with that of the prototype.

Massachusetts Institute of Technology,
Cambridge, Massachusetts

PRESENT STATUS OF THE NATIONAL HYDRAULIC LABORATORY

K. Hilding Beij

(Abstract)

The hydraulic laboratory building was completed March 12, 1932, at a cost of approximately \$300,000. The design, purchase, and installation of equipment are rapidly progressing and it is estimated that experimental work to a limited extent can be

started early in the fall. Most of the first year of operation, however, must be devoted to procurement of equipment and calibration of basins and measuring-apparatus.

Initial pumping-equipment, consisting of five centrifugal pumps, provides for a circulation of 130 cubic feet per second, which is nearly half the designed capacity of the laboratory.

It is expected that the first experimental work will be concerned with flow around pipe-bends and various problems connected with open-channel flow.

Bureau of Standards,
Washington, D. C.

NEW FORMULA FOR PREDICTING ANNUAL RUNOFF OF SOME CALIFORNIA WATERSHEDS

A. F. Gorton

(Abstract)

For some years electric utility companies in Southern California have been using ocean surface-temperatures at La Jolla as an index to the probable runoff in the Owens Valley and Big Creek areas which are important from the standpoint of city water-supply as well as power generation. Recent investigations seem to indicate the possibility of using atmospheric temperatures at San Diego (or Los Angeles) and the advantage of this method is that it permits a comparison of observed and predicted values of runoff for the years prior to the beginning of the ocean temperature-record. Indeed if the method proves to be well founded it will be possible to obtain a check by using the precipitation records in San Diego and Los Angeles which now extend to 1850.

The method consists in correlating the maximum temperature during spring and summer of a given year and the temperature-gradient during late fall with the runoff of the following calendar year--but in so doing using the values not of the actual temperature but of the points on the sum-12 temperature-curve. The latter device is explained in a paper to be read before the Meteorological Section of the Union and is in reality nothing but an elementary smoothing of observed monthly temperature values (in this case air-temperatures at San Diego). It was observed that heavy runoff followed comparatively high values of temperature during the early part of the year coupled with a marked cooling during the late fall, and vice versa, low runoff follows a rising gradient of temperature. Our computations are by no means complete but it appears that the rule held in all but two cases during the last sixteen years.

However, during the years prior to 1916 this formula does not suffice to explain the heavy runoffs that came so frequently. This indicates a certain limitation in the applicability of the theory or a control by a cyclical influence.

Scripps Institution of Oceanography,
La Jolla, California

RAINFALL- AND RUNOFF-CHARACTERISTICS OF THE DELAWARE RIVER BASIN

Clarence S. Jarvis

Rainfall within the Delaware Basin--The lower Delaware River valley has an average annual rainfall slightly above the mean for the known surface of the globe, or about 42 inches. It ranges during a century to less than 30 inches and to more than 60 inches; or in a decade from about 36 to 60 inches. On restricted areas among the highest headwaters along the Catskill Mountains, at elevations of 3,000 feet or more, the precipitation exceeds 65 inches during an average year, while to the leeward at slightly reduced elevations the mean annual rainfall may be 35 inches or less, with proportional ranges from maximum to minimum. As early as March, 1907, this notable deficiency of rainfall on high plateaus in New York and adjoining states was described in the United States Monthly Weather Review by Mr. Thaddeus Merriman, now Chief Engineer of the New York City Board of Water-Supply, whose present duty includes a

development and diversion of water from the Delaware headwaters for the metropolitan district. It is remarkable how thoroughly the additional years of record since 1907 have confirmed those published conclusions as to the depressed isohyets among the sheltered uplands.

The ratios of maximum to mean or of mean to minimum annual rainfall seem to reflect the regularity and dependability of precipitation habits in this region. Tabulations of all such data for the Delaware basin show persistent trends toward such values as 63 : 42 : 28, or perhaps 72 : 48 : 32 inches representing maximum, mean, and minimum annual rainfall, respectively. The successive ratios are seen to be 1.5, somewhat less than should be expected in Florida, or somewhat greater than should be expected in Maine or Vermont, according to Table 1, Rainfall characteristics and their relation to soils and runoff (Trans., Amer. Soc. Civ. Eng., v. 95, 1931, p. 408).

The mean monthly rainfall may vary from about 7.5 to 10.5 per cent of the mean annual depth, in February and August, respectively. This unqualified statement might give the impression of very even distribution throughout the year, while as a matter of fact, the monthly precipitation may range from 0 to 20 per cent or more of the mean annual amount. As a consequence, both floods and droughts are to be provided against within the Delaware watershed. Crops occasionally wither and die in much the same manner as is expected in recognized desert regions; and to avoid such losses, nearly every successful florist, seedsman, nurseryman, or truck gardener is provided with some means of supplementing the natural rainfall. Whether it includes a complete equipment for overhead sprinkling at \$500 per acre, or whether it is only a water-supply facility for the choicest plot, it marks a development in irrigation practice. At this date there are several thousand acres of farm or garden land thus supplied in or adjacent to the Delaware basin.

Delaware River runoff habits--Among the rivers of the eastern section of the United States, only such as the Connecticut, the upper Hudson, and relatively small tributaries originating in upland regions yield as prolifically as does the Delaware. Some of its runoff characteristics are disclosed in the following tabulation for two important stations.

I t e m	Delaware River gaging-station	
	Port Jervis, New York	Trenton, New Jersey
Drainage-area, square miles	3070	6800
Estimated mean annual precipitation in inches, 1902-30	42.80	.....
Above Lambertville-Trenton Station in inches, 1897-30	.....	44.72
Mean annual runoff depth in inches	25.90	24.92
Percentage of mean rainfall appearing as runoff	60.5	55.7
Maximum percentage of mean rainfall appearing as runoff	88.4	72.5
Minimum percentage of mean rainfall appearing as runoff	46.1	41.5
Runoff in cubic feet per second per square mile (c.s.m.)		
Minimum monthly, 1904-29	0.10	....
Minimum monthly, 1915-29	....	0.30
Minimum annual	1.31	1.22
Mean annual	1.84	1.70
Maximum annual	3.22	2.93
Maximum monthly	6.91	5.32
Maximum observed peak	50.5	42.7

It is to be observed that the record for flood-flows extends over a period considerably in excess of a century, while the other data correspond to the 25-year record at Port Jervis or the 16-year record at Trenton. It is probable that the average range of flow during a decade would be approximately one-half of the above.

The dependable yield per square mile above Trenton is nearly 1.9 times that of the Potomac above Point of Rocks, Maryland; 2.3 times that above Ogdensburg, New York, for the St. Lawrence River; or nearly 20 times that of the Colorado River watershed.

The numerous glacial ponds, swamps, and overflow areas among coarse, granular materials seem to have counteracted the influence of steep slopes in the upper Delaware River Basin, so that the stream-flow habits of the headwaters are more nearly like

those of the main stream than is usually observed. The natural regulation there provided has recently been supplemented by such developments as the Wallenpaupack Reservoir and smaller storage projects on the Mongaup River. Further stabilization will probably follow the authorized storage and release of water in connection with New York City's Delaware River diversion plans. Beside controlling the flood-flow from more than 6 per cent of the total drainage-area above Trenton, this project will be required to contribute water from storage whenever the discharge at either Port Jervis or Trenton falls below 0.5 c.s.m.

The total annual runoff from the Delaware River watershed is approximately equal to that of the Colorado River Basin, notwithstanding the disparity in areas. The prevailing gradient above Trenton is comparable with that extending for equal distances above the site of Hoover Dam. A potential market exists for hydro-electric power within 60 to 100 miles of the most promising power-project locations. The water is soft, of exceptional purity, and generally free from silt. It is possible to supply not only the low, but also the intermediate service for metropolitan areas from New York City to Philadelphia by gravity-conduits, the length of which would range from 40 to 120 miles. And yet, in the words of an eminent hydraulic engineer reporting on the possibilities for utilization of this River, "It flows unvexed to the sea."

U. S. Engineer Office, War Department,
Washington, D. C.

CHECKS ON THE MODEL LAW FOR HYDRAULIC STRUCTURES

Morrrough P. O'Brien

Although models of hydraulic structures have been used widely in Europe and this country, the number of quantitative checks on the general validity and limits of applicability of the model laws are not numerous. During the past year, the University of California has begun to develop its hydraulic laboratory so as to include structures as well as machinery and it was thought desirable to confine the first investigations to an attempt at defining the limits of transferability of the results of model tests.

The work described has been performed by graduate and undergraduate students under the supervision of the author. The model laws applying to the class of experiments have been fully outlined by Winkel, Chick, and others (Hydraulic Laboratory Practice, Amer. Soc. Mech. Eng., 1929), and there is no need to include them here.

(1) Sectional models of weirs--These experiments were performed in a rectangular channel one foot wide, equipped with a glass panel 1.5 feet high and 3 feet wide in front of which the models were placed. The water-quantity was measured by means of a diaphragm-orifice which was calibrated volumetrically. Tilting manometers, containing mercury or carbon tetrachloride as needed, were used to measure the differential head.

- (a) Railway embankment (Krimgold-Perko)--The model used was a reproduction to a scale of 1:20 of a standard AREA single-track railway embankment without rails which had previously been tested in full size at the State University of Iowa. The correspondence between model and prototype is shown in Figure 1.
- (b) Round-crested dam (Jackson-Bertelsen)--The models tested were reproductions to scales of 1:7.9 and 1:12 of a dam tested at Cornell and reported on in Water-Supply Paper No. 200 (series 19). The correspondence between models and prototype is shown in Figure 2.

Both of the above experiments show a phenomenon that is characteristic of air-foils and orifices, namely, that the coefficient is constant above a certain value of the independent variable (in this case the head). The point at which the coefficient begins to decrease in the above tests does not follow the model law (Proude Criterion) and the scale-effect is not negligible. The discrepancy is presumably due to viscosity and possibly surface tension.

(2) Pressure- and surface-curves at free overall (Browning-Dauwimer)--The usual treatment of variable flow in open channels assumes that the pressure at the bottom is

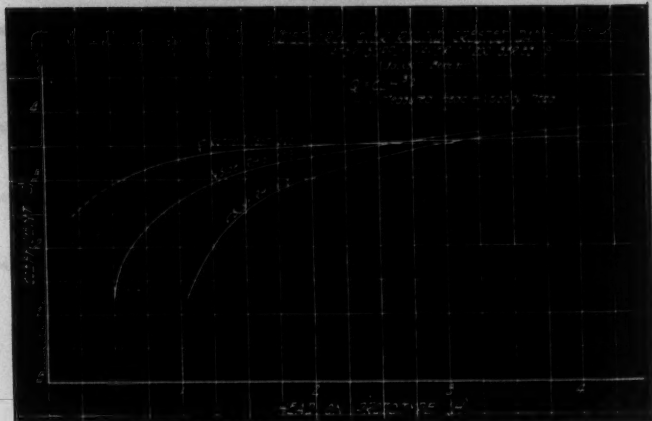


Fig. 1

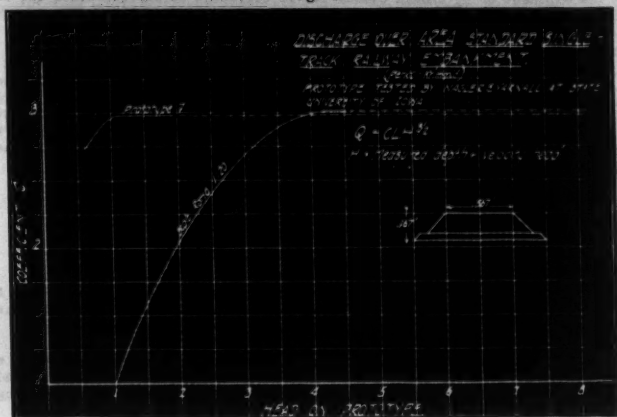


Fig. 2

equal to the unit weight times the depth. This assumption is not valid in the immediate vicinity of a vertical drop at the end of a horizontal channel and the present investigation was undertaken to determine the relation between the surface- and pressure-curves under such conditions.

As an incidental part of this investigation, the relation between the rate of discharge and the depth at the end of the channel was determined and was found to follow the relation

$$Q = 11.0 D_e^{1.61}$$

where Q is the discharge per foot of width and D_e is the depth at the end. The quantity was measured by a diaphragm-orifice which had been calibrated volumetrically.

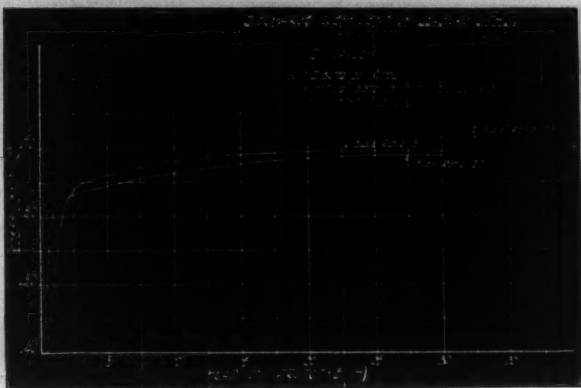


Fig. 3

That the exponent of D_v should exceed 1.5 is difficult to explain since the normal effect of viscosity is to reduce the exponent below this value. The experiments were made with considerable care and the fact to be noted is that, in spite of the high velocity, an appreciable discrepancy exists.

(3) Siphon spillway (H. H. Wheaton)--Models to scales of 1:7.5, 1:15, and 1:20 of one of the Leaburg siphons of the City of Eugene, Oregon, were tested to determine the effect of size on the discharge-coefficient. The smaller models were tested with both free and submerged discharge. The results are shown in Figure 3, where the heads have been multiplied by the scale-ratio. In the region of free discharge, the coefficients are constant but show a slight increase with size as follows:

Scale-ratio	Coefficient
1:7.5	0.715
1:15	0.695
1:20	0.690

The prototype was tested and the measured coefficient was found to be 0.62. Air was leaking into the inlet during these tests and the results for the prototype are not considered as a reliable criterion of the validity of the model law.

A siphon spillway operating with the air-vent sufficiently submerged to eliminate surface-waves at inlet is nothing more than a curved pipe of variable area and it seems that the Reynold's criterion of similarity should be used in correlating experimental coefficients as is done for orifices and Venturi meters.

The head and time required to prime this siphon did not follow the Froude scale-ratio and in fact were found to be approximately the same in both model and prototype. A siphon of another design, however, did follow the scale-ratio approximately in this respect.

(4) River bends (Forney-McNutt)--Three bends of rectangular cross-section with the same depth but with horizontal dimensions in the relation 1:2:4 were used to determine the degree of similarity to be expected in distorted models. Each model at one depth was a distorted model of itself at every other depth and in addition distorted models were obtained by maintaining the same depth at corresponding points on the three models. Experiments were made with both free and submerged discharge at the lower ends with the following results.

- (a) For free discharge, the surface-curves showed marked dissimilarity and the standing waves at entrance were found to have the same length in all the models. This result is to be expected and it points clearly to a limitation in the use of distorted models. With depths corresponding to the horizontal dimensions, the surface-curves were somewhat similar and the discrepancies may have been due to undetectable differences in the inlet-conditions.
- (b) Bottom-currents indicated by streamers were found to follow the same directions in all three models without regard to quantity. In other words, the direction of the currents at the bottom seemed to be determined by the shape of the bend alone and not by the rate of flow.
- (c) Surface-floats made of balsa in sizes to correspond with the horizontal scales and carrying lighted candles were used in an attempt to trace out the surface-currents, but it was found that floats placed at apparently the same point followed vastly different paths and that the paths often crossed.
- (d) Sand in amounts corresponding with the square of the horizontal scales was placed in each model and it was found that at no time was there more than a qualitative similarity. A bar formed at the inside of each bend, but the areas covered were proportionately greater in the small model than in the large one. The scale-ratio between the large and small models was only 1:4 and yet there was little similarity, indicating the possibility of considerable error in using small models even for qualitative studies.
- (5) Wave-motion (C. R. Sexton)--Equations for wave-motion at a free surface follow the Froude relation when friction is not considered and a close correspondence between the measured results and the results computed from such equations would indicate that the model laws would hold for such phenomena. Two different experiments were performed in a glass-sided channel 25 feet long.

- (a) Channel-surges--The channel was placed with its bottom horizontal and flow was set up at the lower alternate stage. A gate at the lower end was then closed quickly and a surge (or traveling hydraulic jump) moved back along the channel. The initial depth and rate of flow, the depth behind the surge and the velocity of advance were measured. The formulas used in computing the depth and velocity are those obtained from considerations of momentum (H. Dahl, Om Svallningar i Kanaler och tuber, Handlingar Nr. 63, Ingenjors Vetenskaps Akademien, Stockholm 1927).

$$\sqrt{d_2} = (1/2\sqrt{g}) (v_1 - v_2) + \sqrt{d_1}$$

$$C = (d_1 v_1 - d_2 v_2)/(d_2 - d_1)$$

$$v_2 = 0 \text{ for complete closure}$$

Here d_2 = depth after surge passes any point; d_1 = initial depth of steady flow; v_1 = velocity corresponding to d_1 ; v_2 = velocity corresponding to d_2 ; and C = velocity of the surge. The computed and measured results were as in the following table.

Discharge	v_1	d_1	Velocity of surge		Difference (C - M)
			Measured	Computed	
sec-ft	ft/sec	ft	ft/sec	ft/sec	per cent
0.35	1.86	0.373	3.26	3.06	-6.1
0.33	1.75	0.374	3.20	3.10	-3.1
0.274	1.65	0.351	3.00	3.02	+0.6
0.282	1.59	0.351	3.00	2.85	-5.0
0.23	1.45	0.314	2.89	2.86	-1.0
0.184	1.32	0.276	2.68	2.68	0.0

- (b) Oscillatory waves--The channel was closed at each end by sand-beaches which prevented reflection of the waves. The paddle of the wave-machine had a sinusoidal profile on the front face and was oscillated in a vertical plane. Both the crank-arm and connecting rod were adjustable so that the submergence of the plunger and the amplitude could be controlled. The velocity, frequency, and amplitude of the waves were measured. In most of the runs,

the depths were greater than half the wave-length. The formulas used in computing the velocity are those given by Gaillard (D. D. Gaillard, Wave-action in relation to engineering structures, Prof. Papers, C. of E., U.S. Army, No. 31, 1904) and are as follows:

$$C = \sqrt{(g/2\pi)}L = \sqrt{5.125}L \quad \text{Deep-water waves}$$

$$C = \sqrt{5.125} (b_v/a_s) L \quad \text{Shallow-water waves}$$

where (b_v/a_s) = ratio of vertical to horizontal axis of elliptical surface-orbits = function of (d_0/L) . The relation between b_v/a_s and d_0/L is most easily represented graphically and the theoretical values used were taken from Gaillard. The computed and measured results were as given in the following table.

Wave-length L	Depth d_0	Ratio b_v/a_s	Velocity of wave		Difference (C - M)
			Measured	Computed	
ft	ft		ft/sec	ft/sec	per cent
0.96	1.009	1.00	2.28	2.22	-2.6
1.27	1.009	1.00	2.42	2.56	+5.7
1.74	1.009	1.00	2.86	2.99	+4.5
1.83	0.805	0.99	2.93	3.05	+4.1
1.32	0.801	1.00	2.50	2.60	+4.0
1.17	0.797	1.00	2.40	2.45	+2.1
1.17	1.600	1.00	2.42	2.45	+1.2
1.65	0.603	0.98	2.86	2.91	+1.7
1.94	0.603	0.96	3.20	3.16	-1.3

Space does not permit a more complete discussion of the individual experiments, but enough has been presented to indicate the possibility of costly errors if models are used without a proper regard for the limitations of the model laws. Experimental checks on the model laws, especially with reference to the transportation of debris, will be continued at the University of California and we may soon be in the unhappy position of having too much data. The man who can draw a curve through one experimental point is as free as the wind, but additional data often bring to light discrepancies difficult of explanation. When several models of the same prototype are constructed to different scale-ratios, an approximation of the accuracy of the predictions for the prototype can be obtained and it appears that too few of these checks have been made in the past.

University of California,
Berkeley, California

A METHOD FOR COMPUTING THE AMOUNT OF EVAPORATION OF SEA-WATER FROM A TANK BY CHANGES IN SALINITY, WITH EXPERIMENTAL RESULTS OBTAINED ON BOARD THE SCRIPPS AUGUST 13-24, 1928

Burt Richardson

Introduction--Roughly half of the radiant energy of the Sun and sky which strikes the surfaces of a body of water goes into evaporation. If this energy strikes an open tank filled with sea-water, the evaporation is accompanied by an increase in the salinity. The quantity of evaporation may be determined by applying a method which involves taking water-samples periodically, and later observing the changes in salinity of the samples.

The theory required by this method will be developed first, and then experimental results of the measurements made on the Scripps August 13-24, 1928, will be given. The amount of evaporation determined by the salinity-method agrees well with amount of evaporation observed.

Notation--The following notation is adopted for use in this paper:

- e = the evaporation in centimeters per unit cross-section
 E = the total evaporation in cubic centimeters
 y_0 = the height of sea-water in tank at time t_0 , when the time-period starts--this height after some evaporation has taken place
 y = the height of sea-water in full tank
 y' = the height of sea-water after time t
 S_0 = the salinity of sea-water in tank at time t_0 when a sample of this water is removed
 S = the salinity of the tank-water after the sample has been removed and the tank replenished--the tank has been filled to a peg
 S' = the salinity of the tank-water at the end of time t
 $\bar{S}$ = the salinity of the replenishing water
 Δ = the increase in salinity in grams of sodium chloride per 1000 cc of salt-water during the time t
 A = the area of the tank in square centimeters
 V = the volume of water when the tank is full
 V' = the volume of water-sample removed
 $\bar{V}$ = the volume of replenishing water (includes evaporation)
 $a = (S' - S)$
 $b = (S_0 - S)$
 $c = (S - S_0)$

Theory covering three cases

(1) The case of a column of sea-water of unit cross-section (Fig. 1)--Consider a column of sea-water of unit cross-section and of original height y cm. The amount of salt in the water at the start is

$$y S \quad (1)$$

where S is the original salinity. After time, t , evaporation has caused the height of the water to decrease from y to y' , and in this process the salinity has increased from S to S' . Hence the amount of salt in any case is

$$y S = y' S' = (y - e) S' \quad (2)$$

Solving for the quantity of evaporation in cm

$$e = y (S' - S) / S' = (y / S') \Delta S \quad (3)$$

(2) The case where the area is not of unit cross-section (Fig. 2)--This case is quite simple; the obvious result is that the evaporation amounts to the evaporation per unit cross-section times the area. However, the mathematical proof follows: The amount of salt present at first is

$$A y S \quad (4)$$

and after time, t , this becomes

$$A y' S' \quad (5)$$

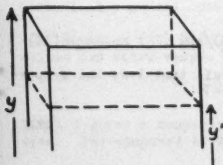


Fig. 1

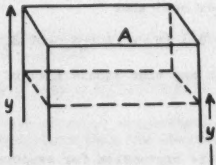


Fig. 2

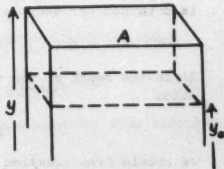


Fig. 3

Since the salt-content during this physical change remains constant

$$A y S = A y' S' = A (y - e) S' \quad (6)$$

Solving for e , the evaporation per unit area

$$e = (y/S') (S' - S) = (y/S') \Delta S \quad (7)$$

and the total evaporation in Δt is given by

$$E = A e = A y (S' - S)/S' = A (y/S') \Delta S \quad (8)$$

(3) The case where samples of sea-water are periodically removed from the tank, which is in turn replenished by water of known salinity and of an amount equal to the water-sample removed plus the evaporation-quantity (Fig. 3)--The problem here is to express evaporation as a function of changes in salinity, the dimensions of the tank, and certain constants. The quantity of salt present in the sea-water for the quite general case after some evaporation has taken place is expressed by

$$A y_0 S_0 \quad (9)$$

where A is the area in square cm, y_0 is the height in cm, and S_0 is the salinity (grams of sodium chloride per 1000 cc of sea-water). Then a water-sample of volume V' is withdrawn which contains salt of the amount

$$V' S_0 \quad (10)$$

and accordingly the quantity of salt remaining in the tank is

$$A y_0 S_0 - V' S_0 \quad (11)$$

Immediately thereafter a volume of water V of known salinity S is poured into the tank to replace the sample as well as the quantity of water lost by evaporation. The tank is filled to a constant level. Now the amount of salt in the tank is

$$A y_0 S_0 - V' S_0 + \underline{V S} \quad (12)$$

while the salinity at the start of a run, that is, when a water-sample has been removed and the tank replenished, is given by the expression

$$S = (A y_0 S_0 - V' S_0 + \underline{V S})/A y \quad (13)$$

At the end of time, t , the salinity has increased from S to S' . Now since the amount of salt in the tank remains constant during the evaporation-period

$$A y S = A y' S' = A (y - e) S' \quad (14)$$

and solving for the evaporation, per unit area

$$e = y \Delta S / (S + \Delta S) = y (S' - S) / S' \quad (15)$$

Now by the substitution of the value for S as given by equation (13), an expression is obtained for evaporation per unit area

$$e = (y/S') [S' - (A y_0 S_0 - V' S_0 + \underline{V S})/A y] \quad (16)$$

Since the depth of the tank at any time equals that of the full tank less the evaporation

$$y_0 = y - e \quad (17)$$

we obtain from equation (16) the expression for evaporation

$$e = [y (S' - S_0) + V' S_0 / A - \underline{V S} / A] / (S' - S_0) \quad (18)$$

Now, since the volume of the replenishing water at the end of time t always equals the volume of the sample removed plus the evaporation loss, that is,

$$\bar{v} = v' + E \quad (19)$$

by making this substitution in equation (18) an equation is obtained which is more useful for it does not require a knowledge of the quantity of replenishing water.

$$e = [y (s' - s_0) + (v'/A) (s_0 - \underline{s})] / (s' - s_0 + \underline{s}) \quad (20)$$

The evaporation in cc equals

$$E = A e = [V (s' - s_0) + v' (s_0 - \underline{s})] / (s' - s_0 + \underline{s}) \quad (21)$$

where the tank-evaporation is expressed as a function of three salinity-values and two constants, the volume of the full tank and the sample.

For serial computations

$$E_1 = [V (s_2 - s_1) + v' (s_1 - \underline{s})] / (s_2 - s_1 + \underline{s}) \quad (22)$$

$$E_2 = [V (s_3 - s_2) + v' (s_2 - \underline{s})] / (s_3 - s_2 + \underline{s}) \quad (23)$$

$$E_3 = \dots \dots \dots, \text{etc.}$$

A further simplification can be made in equation (21), due to the fact that the magnitude of the sea-water salinities along the California Coast during the summer months varies only between 33 and 37, by letting

$$a = (s' - 33) \quad (24)$$

$$b = (s_0 - 33) \quad (25)$$

$$c = (\underline{s} - 33) \quad (26)$$

Finally evaporation in cc equals

$$E = [V (a - b) + v' (b - c)] / [33 + (a - b + c)] \quad (27)$$

The computation of evaporation from the Scripps
tank by means of salinity-changes

Dimensions of tank--Water in tank, 44.5 × 44.5 × 37 cm; area of water-surface, 1985 sq cm; volume of water, 73,480 cc. The tank was mounted on double gimbals so that motion of the boat would not disturb the water-surface. The water-level remained 10 cm below the top of the tank.

Method--A 500-cc sea-water sample was removed from the tank aboard the Scripps five times per day. Each sample was then numbered for later salinity-determinations. At the time of the sample withdrawal, the tank was replenished by water of known salinity of an amount equal to the sample removed plus the quantity evaporated. During the experiment the water-level was kept at a constant height, that is, water was periodically poured into the tank until it reached the top of a peg.

Equation (27) in this particular experiment (by the substitution of the tank-volume and water-sample values) becomes

$$E = (147a - 146b - c) / [0.066 + (a - b + c)/500] \quad (28)$$

Table 1 gives a comparison of the observed evaporation and that computed from salinity-data. The computed is 9 per cent less than the observed.

Table 1--Evaporation in cubic centimeters

Date	Change in salinity in hundredths	Computed	Observed	Date	Change in salinity in hundredths	Computed	Observed
1928				1928			
Aug. 13	12	304	235	Aug. 20	7	226	410
	14	363	20		0	64	135
	7	200	280		0	64	55
	10	274	430		12	315	110
		<u>1141</u>	<u>955</u>		4	<u>152</u>	<u>60</u>
Aug. 14	- 4	- 38	155			821	770
	0	52	70	Aug. 21	12	330	400
	12	304	105		0	78	190
	7	<u>215</u>	<u>280</u>		. 4	167	305
		<u>533</u>	<u>610</u>		- 2	<u>34</u>	<u>30</u>
Aug. 15	9	244	380			609	925
	0	52	130	Aug. 22	3	137	500
	3	111	110		8	240	55
	10	274	135		6	211	190
	13	<u>354</u>	<u>165</u>		3	137	130
		<u>1015</u>	<u>920</u>		6	<u>196</u>	<u>20</u>
Aug. 16	3	126	320			921	855
	0	66	90	Aug. 23	5	181	110
	0	66	135		1	94	210
	9	259	220		- 1	50	135
	5	<u>171</u>	<u>180</u>		1	94	15
		<u>688</u>	<u>945</u>		4	169	230
Aug. 17	12	319	400		1	<u>242</u>	<u>85</u>
	- 2	22	175			830	785
	5	171	145	Aug. 24	1	108	330
	5	185	20		2	123	185
	3	- 23	85		5	182	80
		<u>674</u>	<u>825</u>		1	93	25
Aug. 18	18	447	520		0	78	40
	- 2	34	235		1	<u>108</u>	<u>100</u>
	- 6	- 55	100			692	760
	9	<u>256</u>	<u>20</u>	Computed grand total		9224	.....
		<u>682</u>	<u>875</u>	Observed grand total		....	10125
Aug. 19	11	303	230	Difference (O - C)		9 per cent	
	- 6	- 40	190				
	0	64	355				
	6	197	100				
	3	<u>123</u>	<u>5</u>				
		<u>617</u>	<u>880</u>				

Scripps Institution of Oceanography,
La Jolla, California

PROBLEMS OF UNDERGROUND WATER-FLOW IN THE OIL INDUSTRY

Morris Muskat

Paradoxical as it may seem, it is nevertheless true that the oil industry is vitally interested in the general problem of underground water-movements. Indeed, its interest is not an academic one. Yet its great importance to the oil industry affords and supplies an enthusiasm in the problem probably comparing favorably with that of the pure science devotees in our academic institutions.

The basis of this significance is twofold in character. First, the almost universal occurrence of ground-waters in the immediate neighborhood of an oil-sand requires of the petroleum engineer that he fully understand the reactions of these waters to the changes in the pressure-conditions in the oil-sand produced by the drilling of wells and depletion of the oil. Secondly, the physicists in the oil industry engage in the study of underground movements of water as a prototype and idealization of the vastly more complicated and yet unsolved problem of the underground movement of gas-oil mixtures, in which, of course, he is principally interested. Although it is only recently that a scientific mode of attack has been applied to these problems by people in the oil industry, the fruits of their efforts are already not far from view.

The problem of the encroachment into an oil-horizon of the ground-waters flanking an oil-sand is one of the most important with which the operators of an oil-pool have to deal. If the water-entry is controlled carefully by a proper spacing and operation of the oil-wells, it may afford a drive upon the oil and be a definite aid in the production. If, however, it is unrestrained in its encroachment the flanking water may under certain conditions flood the oil-sand in an undesirable manner and prevent the oil from entering the wells.

Specifically the question must be answered as to the effect of various modes and rates of production upon the water encroachment and then the reaction of the latter upon the production. Unfortunately, however, the answer to this question cannot be given in general terms without qualifications. For it must be admitted that regardless of the method of operation of the oil-field, the water must ultimately flood the sand and reach the wells simply because the pressure in the oil-sand is continually lowered as the oil is removed. Nevertheless, the details of this flooding, and hence the amount of oil and water that will be produced until the flooding makes further operation unprofitable, will depend on the method of operation of the field.

Thus a slow rate of depletion of the field will permit the water to keep pace with the oil and even impart to it a hydrostatic drive aiding the oil in the flow. A rapid depletion will result in lowered pressures at the water-oil boundary and permit a maximum water-encroachment which, however, may not suffice to keep up with the oil-flow driven by its more energetic internal gas-drive. Not only will the benefits of the hydrostatic drive then be lost but more serious effects may ensue. Aside from the problem of coning to be described presently, which may result from the uncontrolled production, the following situation may arise, especially where the rapid production is coming from a few wells near the water-oil boundary. The low pressures at these wells will produce a fingering of the water about them. The wells will go rapidly to water and when closed in because of excessive water production, they will drive the surrounding water to neighboring wells. If these latter had been produced slowly the water from the flooded wells may be closer to the neighboring wells than the main water-oil boundary. This may lead to a trapping of the intervening oil and their effective loss as immediate potential oil production.

Finally, it appears reasonable that the effectiveness of the flooding of an oil-sand by water will be greater if the oil is a homogeneous liquid mass than if it be a gas-oil mixture with the individual gas bubbles trapped in the sand pores. Hence a slow depletion of the field will mean that the pressures at the oil-water boundary will be high and the oil will have but little free gas mixed with it. If, however, the field is depleted so rapidly that the water cannot keep pace with the oil-flow, the water will find a mass of gas bubbles with enveloping oil-films, when it finally en-

croaches into the oil-sand. The flooding power of the water in this case will probably be less efficient and the oil unrecovered will be correspondingly higher.

Although these qualitative conclusions seem reasonable physically, one must make detailed calculations in each particular case when quantitative information is desired. These may be carried through on the basis of D'Arcy's law for the flow of liquids through sands, together with a knowledge of the pressures at the oil-water boundary and the position of the water-outcrop. The permeability of the sand must also be known and a systematic permeability technique has been developed for this purpose.

Another important problem, dealing with ground-waters existing in what may be considered as a semi-static state, however, is that known in the oil industry as water-coning. The situation, here, is that in which the water lies beneath the oil-sand or at least below some of the wells drilled into the oil-zone. Because of the greater density of the water, the pressure gradients which are able to drive and lift the oil into the well may not suffice to overcome the vertical gravity-force on the water and lift it, too, into the well. The water then will lie statically underneath the oil-zone with an elevated or curved surface in equilibrium with the pressure distribution in the oil-zone. If, however, the rate of oil-flow is sufficiently high the correspondingly high-pressure gradients will exceed the gravity-head of both the oil and water and hence will lift them both into the well. Once the water is set in motion its greater mobility comes into play with the result that it tends to displace the oil and produce a well flowing mostly water. Unfortunately, such situations as these occur very frequently with wells sunk deep in the sand and producing without the proper control. Under certain simplifying assumptions the solution of this problem can be carried through and the methods of preventing the water-cone are clearly indicated by the analysis.

These are examples of situations in which the petroleum engineer has thrust upon him the problem of underground water-movements. But apparently he does not dislike the problem. For, not only is he forced to acquire an understanding of ground-water movements because of the frequent natural occurrence of ground-waters in the immediate vicinity of oil-sands, but he often finds it profitable to produce artificially for himself a water problem. As an example of such a situation may be cited the flooding operations in the Bradford field in northwestern Pennsylvania. The practical problem involves the pumping of water into certain key wells for the purpose of flooding out the oil remaining in the sand after the application of the usual production methods. An idea as to the motion of this input-water, the pressures required for given rates of flow and at least a qualitative prediction as to its effectiveness in driving the oil to the output-wells can only be obtained from a clear understanding of the physics of underground water-flow.

The practical value of these flooding operations are qualitatively indicated by the observation that whereas before the flooding program was undertaken the Bradford field had been exhausted to its economic limit of production, still, for the last several years the operations have again been flourishing there with remarkable profit in spite of the large investments required to carry out the flooding program. Another striking proof of the significance to the oil industry of a knowledge and understanding of the motion of water in underground sands is afforded by a comparison of the average percentage oil-recovery from fields with and without controlled water-flooding. Thus in the Glenn Pool in Oklahoma, produced by the usual methods without the aid of water-movements but even with the application of a vacuum, we have a representative recovery value of 20 per cent of the original oil in the pool. On the other hand, in the Wortham and Powell fields in Texas, where the naturally occurring ground-waters had a sufficiently effective artesian flow to follow up the oil-depletion and slowly and regularly flood the sands, the recoveries averaged 45 per cent. It is very probable that in these latter cases a disregard and misunderstanding of the physics of the flow of the underground waters would have led to serious detrimental effects rather than the extremely profitable results indicated by the high-percentage recoveries.

As important as these applications of the theory of underground water-movements are to scientific progress in the oil-industry the still more fundamental problem remains of understanding the flow of the oil itself. Because, however, the oil in the

early life of a pool flows as an oil-gas mixture, continually exuding gas which itself expands as the well is approached, the validity of Darcy's law cannot be assumed without definite experimental verification. Since such a verification has not been established as yet, nor has a substitute law been developed, simplifications have to be made. The most reasonable simplification appears to be that in which the oil-gas mixture flow is replaced by its prototype of a gas-free water-flow of equivalent viscosity. This idealization, in addition to its simplicity, has the following physical justification. When high back-pressure is maintained on a pool as is the usual practice in oil-fields under proration, or, when a pool is pretty much depleted, there is relatively little free gas flowing through the sand-body and the oil does behave much as a dead liquid. Furthermore, since we know the qualitative effects of the free gas, such as its concentration of the pressure-gradients about a well, we can estimate with some certainty the conditions in a flow-system where gas may be present, if we know the conditions in the equivalent water-flow system and the type of changes produced by the presence of the gas.

From this point of view considerable attention has been devoted to solutions of Laplace's equation, which determines the pressure-distribution in a water-bearing sand, for geometrical systems corresponding to situations of practical interest. A number of these had already been solved by Prof. C. S. Slichter in his classic work published in the United States Geological Survey of 1897-98. These have been extended and applied to other cases of more interest to the oil-industry, and they have been studied from an experimental, as well as an analytical point of view.

Two examples of such investigations possibly worthy of mention are the problems of partially penetrating wells and of gravity-flow of liquids in sands. The former was studied in connection with the problem of water-coning, already mentioned. Thus because of the danger of the underlying water flowing into a well, they are often drilled so as to penetrate the sand only partially and hence lessen the probability of water-coning. The flow to be expected for such wells for various penetrations and sand-thicknesses, and the pressure-distributions about the wells were among the results derived from the analysis.

The problem of the flow of gas-free liquids under the action of gravity is perhaps of still more importance in the field of hydrology than in the domain of oil-production although recently its significance in oil-flow has also been shown to merit attention. Much work has previously been done on the subject, especially in the European countries. However, nothing conclusive or general seems to have resulted from these investigations. The problem presents great analytical difficulties, because of the fact that the upper free surface in a gravity-flow system is unknown and has to be determined simultaneously with the solution of the pressure-distribution problem. A carefully controlled experimental investigation, together with some general theoretical arguments have finally led to a unique solution to the problem and such that it could be given a general formulation, not only with respect to the geometry of the flow-system but also so as to include the added effect of non-gravity pressure-drives as well.

These examples will suffice, it is hoped, to indicate the type of underground water-problems of interest and importance to the oil-industry. Even though the goal is admittedly utilitarian, it is well appreciated that only physically sound methods of attack such as used in academic investigations, can be relied upon to bring the desired results. Unquestionably the people in the oil-industry will find much to learn in familiarizing themselves with the work of and cooperating with those interested more particularly in hydrology where the scientific approach to the problem has been an axiom of long standing.

Gulf Research Laboratory,
Pittsburgh, Pennsylvania

BLANK PAGE